NCHRP

RESEARCH REPORT 833

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Assessing, Coding, and Marking of Highway Structures in Emergency Situations

Volume 1: Research Overview

TRB TRANSPORTATION RESEARCH BOARD

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Volume 1: Research Overview

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SCIENCES · ENGINEERING · MEDICINE

2016

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

Recognizing this need, the leadership of the American Association of State Highway and Transportation Officials (AASHTO) in 1962 initiated an objective national highway research program using modern scientific techniques—the National Cooperative Highway Research Program (NCHRP). NCHRP is supported on a continuing basis by funds from participating member states of AASHTO and receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine was requested by AASHTO to administer the research program because of TRB's recognized objectivity and understanding of modern research practices. TRB is uniquely suited for this purpose for many reasons: TRB maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; TRB possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; TRB's relationship to the Academies is an insurance of objectivity; and TRB maintains a full-time staff of specialists in highway transportation matters to bring the findings of research directly to those in a position to use them.

The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments and by committees of AASHTO. Topics of the highest merit are selected by the AASHTO Standing Committee on Research (SCOR), and each year SCOR's recommendations are proposed to the AASHTO Board of Directors and the Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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The **National Academy of Sciences** was established in 1863 by an Act of Congress, signed by President Lincoln, as a private, non-governmental institution to advise the nation on issues related to science and technology. Members are elected by their peers for outstanding contributions to research. Dr. Marcia McNutt is president.

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Learn more about the Transportation Research Board at **www.TRB.org**.

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The research reported herein was developed for NCHRP Project 14-29 by Oregon State University (OSU), Merrimack College, University of Missouri–Kansas City (UMKC), MPN Components, Inc., and Advanced Infrastructure Design, Inc. (AID). The authors of the report are: Michael J. Olsen (OSU), Andre Barbosa (OSU), Patrick Burns (OSU), Marc Veletzos (Merrimack), Zhiqiang Chen (UMKC), Gene Roe (MPN), Kaz Tabrizi (AID), Alireza Kashani (OSU), and Haizhong Wang (OSU).

The authors appreciate those who responded to the questionnaire and provided the research team with information regarding current processes of state DOTs. In addition, we are thankful for the detailed reviews of the project panel that improved the content of the products of this project.

FOREWORD

By Amir N. Hanna
Staff Officer
Transportation Research Board

This report presents a process for assessing highway structures in emergency situations and guidelines for related coding and marking that can be recognized by highway agencies and other organizations that respond to emergencies resulting from natural or man-made disasters. This information will help highway and other emergency response agencies deal more effectively with these emergencies and provide a safer condition for the public. The material contained in the report should be of immediate interest to the personnel at state agencies and other organizations that generally respond to emergency situations affecting highway structures.

The assessing, coding, and marking of highway structures are necessary for ensuring safety in the event of emergencies resulting from natural or man-made disasters, and several state DOTs have adopted processes for performing these activities. However, there are currently no processes that provide a uniform means for conducting these assessments or a common form of coding and marking; neither do current processes explicitly consider the practices of other organizations that often respond to such emergencies with assistance. Also, these processes do not generally address the full range of emergency events, the different highway structure types, or the ranges of traffic levels. These issues tend to impede the effectiveness of involved organizations in dealing with these situations and may lead to undesirable consequences. Research was needed to develop a process for assessing highway structures and guidelines for related coding and marking that can be recognized and adopted by highway agencies and other organizations. These uniform processes and guidelines would help coordinate the emergency response effort in a safe and efficient manner.

Under NCHRP Project 14-29, "Assessing, Coding, and Marking of Highway Structures in Emergency Situations," Oregon State University worked with the objective of developing (a) a process for assessing highway structures in emergency situations, (b) guidelines for coding and marking, and (c) material to facilitate the acceptance and adoption of the developed process and guidelines by state agencies and other organizations.

The research was conducted in two phases. The first phase collected background information through a literature review and a survey of state departments of transportation. The review dealt with common hazards, critical highway structures, inspection technologies, emergency management and response, assessment procedures, and coding and marking practices. Specific hazards considered included earthquakes, tsunamis, tornados, hurricanes, storm surge, high winds, flooding, scour, and fire. Highway structures considered included bridges, tunnels, culverts, walls, embankments, and overhead signs. This work identified assessment, coding, and marking technologies that can be practically implemented by transportation and other emergency response agencies. An evaluation of these technologies led

to the identification of methods that could be used in each stage in the process for rapid assessment of highway structures in emergency situations.

The second phase of research focused on developing the (a) *Assessment Process Manual* and (b) *Coding and Marking Guidelines.* The *Assessment Process Manual*—intended for managers who will oversee the emergency response—identifies technologies that are appropriate for each structure type and addresses prioritization, coordination, communication, and redundancy. The *Coding and Marking Guidelines* are intended as a field manual for preliminary damage assessment responders who will evaluate the highway structures. In addition, the project produced Preliminary Damage Assessment Forms for each structure type, development guidelines to help create a mobile device smart application for the assessment process, and four types of training material to further help highway agencies and other emergency response organizations with the implementation of the developed manual and guidelines. This training material includes: (a) general training for the general audience who will interface with those involved in the assessment process, (b) basic training for damage assessment responders, (c) specialized training for managing engineers who will oversee the assessment process, and (d) a quick refresher for damage assessment responders on the most relevant procedures for Preliminary Damage Assessment.

The *Assessment Process Manual* and *Coding and Marking Guidelines* are published as Volumes 2 and 3, respectively, of this report. *Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations* is available on the TRB website (www.trb.org) as *NCHRP Web-Only Document 223.* To facilitate use, the assessment forms and training material are posted on the *NCHRP Research Report 833* summary page, available by searching the TRB website for NCHRP Research Report 833.

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SUMMARY

Assessing, Coding, and Marking of Highway Structures in Emergency Situations: Research Overview

The assessing, coding, and marking (or sometimes referred to as "posting") of highway structures is necessary to ensure the integrity and usability of highway structures before, during, and after emergency events such as earthquakes, tsunamis, tornadoes, hurricanes, storm surge, high winds, flooding, scour, and fire. Orderly evacuation, when necessary, and subsequent emergency response require that bridges, tunnels, walls, culverts, embankments, and overhead signs be capable of safely supporting necessary loads and functioning satisfactorily. In addition, geotechnical and hydrological issues affecting these structures such as slope stability, liquefaction, settlements, and scour must also be considered.

Not only is the highway network relied upon to transport people, but it is also the economic lifeline of the affected region facilitating the movement of emergency supplies and services. Restoring power, supplying fuel, transporting injured residents, and providing food stocks can be just a few of the critical needs of a region affected by a catastrophic event.

As seen over the past few years with disastrous events such as the 2012 Hurricane Sandy and the 2011 Tohoku earthquake and tsunami in Japan, the need for emergency preparedness planning is essential to a coordinated, timely, and effective response, particularly in terms of communication between the various agencies that need to be involved. The extent of advance notice will depend on the type of event, but, in all cases, the greater the level of planning and interagency discussions that can be performed to analyze a range of what-if scenarios, the better.

One of the critical components of any emergency response plan is the process for inspectors to assess the integrity of highway structures impacted by an event. To date, a uniform methodology for rapidly assessing, coding, and marking highway structures after an emergency event does not exist. Current processes do not generally address the different highway structure types, the full range of emergency events, the range of traffic levels (i.e., the amount of traffic that a highway structure normally carries), or methods employed by other responding agencies. To this end, the primary purpose of this report is to establish a uniform methodology along with a consistent framework for coordinating the emergency response effort in a safe and efficient manner. This scalable approach provides guidance on response levels based on the severity of the event.

In fact, this recommended approach to the issue of structural assessment is based on a "First You Plan" strategy. During this vital planning phase, regional factors, interagency needs, and communication issues can be identified and addressed in a non-emergency environment. Access by inspectors to all available information (which can vary significantly) can be planned and tested under simulated event conditions (e.g., ShakeOut earthquake drills).

The assessment process presented in this report consists of four stages: Fast Reconnaissance (FR), Preliminary Damage Assessment (PDA), Detailed Damage Assessment (DDA), and Extended Investigation (EI).

This hierarchal approach accounts for the need for rapid yet reliable information at the early periods of the emergency situation followed by progressively more detail as the process continues to ensure appropriate allocation of resources during the repair and recovery phase. The approach also accounts for the diverse skill sets and capabilities of persons needed for the assessment process. Finally, it provides guidance for determining appropriate response levels and mobilization based on incoming warnings or information for each emergency event.

Given the immense scope and ranges of damages from the plethora of emergency events possible across the country, the assessment procedure was developed with a simplified taxonomy in order to group common forms of damages so that a systematic process could be implemented that is nearly independent of the hazard type.

A coding and marking procedure was developed for use after the assessment is completed where each structure is physically marked with a placard and digitally marked in a database to improve communication between responders for various organizations. The coding and marking following a PDA stage establishes whether a structure has been INSPECTED or is UNSAFE. Quick-response (QR) codes are also used on these placards to link and communicate important structural or other information to field responders.

Technology is a critical component for recording and communicating these assessment results. It can help improve the process if staff are appropriately trained and prepared to utilize the technology. For example, a geographic information system (GIS) database for the structures that was prepared (and continually updated) prior to the event can be used to help prioritize assessment routes, track progress, and analyze the condition of the highway network in order to provide decision makers with up-to-date information.

Incoming data from video networks, crowdsourcing, and other sources can be quickly collected to help determine the optimal locations to send personnel for rapid inspections. While a human-centered, visual assessment process is recommended for the PDA stage, this process can be guided and enhanced through the use of applications on smart devices that enable information to be systematically recorded and routed back to the central office. In the later stages, performing more detailed assessments can also benefit from more advanced tools and resources.

Providing PDA responders (from all responding agencies) with a uniform process will help to support the overall emergency response framework, regardless of the scale of the event. Nonetheless, it is recognized that each agency will have different capabilities, resources, organizational structures, challenges, and priorities. Hence, the assessment process was developed to identify and recommend methodologies that can be practically implemented by today's state highway agencies, along with the training materials to support these activities.

CHAPTER 1

Introduction

1.1 Background and Problem Statement

Several state departments of transportation (DOTs) have adopted processes for the assessing, coding, and marking of highway structures in the event of emergencies resulting from natural or man-made disasters. However, these processes do not provide uniform means for conducting these assessments or a common form of coding and marking. Also, these processes do not generally address the different highway structure types or the range of traffic levels. In addition, many of these processes do not explicitly consider the practices of other organizations that often respond to such emergencies with assistance. These issues tend to impede the effectiveness of involved organizations in dealing with these situations and may lead to undesirable consequences.

The assessing, coding, and marking of highway structures are necessary for ensuring safety in the event of emergencies. However, there is a need for employing uniform processes for conducting these assessments and guidelines for coding and marking. A widely accepted process is not currently available; this project was conducted to develop a process for assessing highway structures and guidelines for related coding and marking that can be recognized and adopted by highway agencies and all other organizations that respond to such emergencies. This information will help highway agencies and these organizations deal more effectively with the situation and provide a safer condition for the public.

1.2 Research Objective

The primary objectives of this project were to develop the following:

- A process for assessing highway structures in emergency situations
- Guidelines for coding and marking
- Selected training and implementation material

The materials developed to satisfy these objectives were prepared as stand-alone products to help facilitate acceptance and adoption by AASHTO and other organizations generally responding to emergency situations affecting highway structures.

1.3 Research Scope and Approach

The research was divided into two phases. The first phase focused on acquiring background information. The second phase consisted of developing the assessment process and materials to support the implementation.

The initial phase of this project focused on identifying and recommending assessment, coding, and marking methodologies that can be practically implemented by today's transportation and

other emergency response agencies. A comprehensive literature review was conducted to research common hazards, critical highway structures, inspection technologies, emergency management and response, assessment procedures, and coding and marking practices. Specific hazards considered include earthquakes, tsunamis, tornados, hurricanes, storm surge, high winds, flooding, scour, and fire. Highway structures considered include bridges, tunnels, culverts, walls, embankments, and overhead signs. While the focus was on practices related to highway structures, the research team also considered practices for non-highway structures such as buildings that were relevant. Only citable, publicly accessible material was included in this literature review.

Simultaneous with the literature review, a questionnaire was distributed from February 24 to April 3, 2014, to the current membership of the AASHTO Subcommittee on Bridges and Structures, Subcommittee on Maintenance, and Special Committee on Transportation Security and Emergency Management. This questionnaire enabled the team to obtain current DOT procedural manuals that are difficult to find via conventional means. It was also helpful in obtaining information on current practices and capabilities.

From these efforts, the team was able to identify and evaluate appropriate practices and technologies relevant to assessing, coding, and marking highway structures in emergency situations. After this evaluation, the research team recommended methods that could be used in a process for rapid assessment of highway structures in emergency situations appropriate for nationwide adoption.

Following successful completion of the first phase, the research team utilized this information in the second phase as follows:

- To develop a process for assessing highway structures, including identifying which technologies are appropriate for specific structure types, prioritization, coordination, communication, and redundancy. This process has a multi-tiered, priority-based approach so that personnel with varying levels of expertise will be able to use them.
- To write guidelines suitable for adoption by AASHTO for the coding and marking of highway structures.
- To prepare high-impact training programs and supporting materials to ensure the effective implementation of the assessment process and guidelines.

At the final stages of the research project following NCHRP review and approval, a special workshop was convened with representatives from nearly 25 state highway agencies (SHAs) who serve on AASHTO committees. The objective of this workshop was to facilitate the implementation of the research by informing the attendees of the project's products as well as to identify next steps to facilitate AASHTO adoption. Feedback from the attendees of the workshop was also incorporated in the final products to the extent possible.

1.4 Organization of the Report and Associated Products

NCHRP Research Report 833 comprises three volumes. This volume provides background information on the assessing, coding, and marking of highways structures. It also provides a brief overview of the process, supporting manuals, and training materials, which are available as separate volumes and products. This volume is divided into the following chapters:

- Chapter 2 presents a concise summary of the state of the art and state of the practice for the assessing, coding, and marking practices determined through a literature search and questionnaire.
- Chapter 3 evaluates current and emerging assessment techniques as well as coding and marking practices.
- Chapter 4 provides an overview of *Volume 2: Assessment Process Manual*, which is meant to support management in overseeing the assessment process.

- Chapter 5 contains an overview of *Volume 3: Coding and Marking Guidelines.* The coding and marking guidelines were developed for the Preliminary Damage Assessment (PDA) responders (PDARs).
- Chapter 6 presents an overview of *NCHRP Web-Only Document 223: Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations.*
- Chapter 7 introduces the various types of training materials and products available through this project.
- Chapter 8 presents an implementation plan, describing effective approaches to integrating this process into an organization.
- Chapter 9 presents conclusions and an outlook on the future in emergency assessments.

The main text is followed by references, a list of acronyms and abbreviations, and a glossary.

Volumes 2 and 3 are bound separately:

- *Volume 2: Assessment Process Manual*—This volume describes the assessment process in detail, particularly the planning and preparation phase. It is meant for managers who will be overseeing the emergency response.
- *Volume 3: Coding and Marking Guidelines*—This volume is meant as a field manual for PDARs who will be evaluating the highway structures.

Additionally, several associated products are available on the TRB website (www.trb.org) by searching for "NCHRP Research Report 833". A brief description of each follows:

- *NCHRP Web-Only Document 223: Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations*—This document is provided to facilitate communication with information technology (IT) staff on how to create applications (apps) for mobile devices to help with the assessment process.
- Preliminary Damage Assessment Forms—Microsoft® Word™ files containing the assessment forms for each structure type as well as full-size pages.
- Training Materials—Several forms of training materials for four workshops were produced, including Microsoft PowerPoint™ modules with instructor's notes. The four workshops are as follows:
  - General Training—A 1-hour presentation that provides general background and high-level key points for the project. This is meant for a general audience who will be interfacing with those involved in the assessment process but will not be heavily involved.
  - Basic PDAR Training—Several PowerPoint modules meant for training PDARs.
  - Specialized Managing Engineer Training—Several PowerPoint modules to help train managing engineers who will oversee the assessment process.
  - PDAR Quick Refresher—A simplified 30-minute version of the training for the most important procedures related to PDA that can be given immediately prior to sending PDARs in the field.

CHAPTER 2

State of the Art and State of the Practice: Literature Review and Questionnaire

2.1 Introduction

This chapter describes key findings from a literature review and questionnaire conducted to determine the state of the art and the state of the practice related to the assessing, coding, and marking of highway structures during emergency situations.

A comprehensive literature review was conducted to research common hazards, critical highway structures, inspection technologies, emergency management and response, assessment procedures, and coding and marking practices. Specific hazards considered include earthquakes, tsunamis, tornados, hurricanes, storm surge, high winds, flooding, scour, and fire. Highway structures considered include bridges, tunnels, culverts, walls, embankments, and overhead signs. While the focus was on practices related to highway structures, the research team also considered practices for non-highway structures such as buildings that were relevant. Only citable, publicly accessible material was included.

A questionnaire was distributed from February 24 to April 3, 2014, to the membership of the AASHTO Subcommittee on Bridges and Structures, Subcommittee on Maintenance, and Special Committee on Transportation Security and Emergency Management. In addition, state TRB representatives were contacted to distribute the questionnaire to appropriate personnel. This questionnaire enabled the team to obtain current DOT procedural manuals that are difficult to find via conventional means.

A total of 59 complete responses representing all 50 state DOTs were obtained. Additional partial responses were obtained but not used in the analysis. The respondents consisted of personnel from maintenance, operations, bridge, and structures divisions. Of these, the respondents contained a mix of inspection/maintenance engineers, bridge engineers, and managers. Hence, the questionnaire response group contains input from the various divisions and personnel responsible for conducting structural assessments and maintaining those structures.

2.2 Assessment Procedures

Assessment is the process of evaluating a structure's condition through inspection and/or analysis. This evaluation can be completed manually (i.e., visually) or through technological means. There are numerous documents in the literature describing the assessment of structures during both emergency and non-emergency situations that are relevant to the aims of this project. This section organizes these documents based on their scope. In general, guidelines and procedures tend to take a broad view of the assessment process, while inspection techniques tend to be limited to a specific structure type/component, material, or hazard. Because relatively limited procedures are available for assessment of highway structures in emergency situations, relevant

procedures for buildings were reviewed first as an introduction to some practices that were useful for understanding the operations involved in assessment of structures. Finally, hazard-specific guidelines and assessment procedures manuals currently employed by several DOTs were reviewed. Related coding and marking practices are discussed in Section 2.3.

2.2.1 Guidelines and Procedures for Emergency Situations

2.2.1.1 Buildings

The Applied Technology Council's ATC-20 series of documents are the most used and referenced set of documents regarding the assessment of buildings in emergency situations. Although developed for buildings, most highway structure evaluation procedures are rooted in this approach. This series was developed for post-earthquake assessment of buildings and includes the following:

- ATC-20 *Procedures for the Post-earthquake Safety Evaluation of Buildings* (ATC 1989)
- ATC-20-1 *Field Manual: Procedures for the Post-earthquake Safety Evaluation of Buildings* (ATC 2005)
- ATC-20-2 *Addendum to the ATC-20 Post-earthquake Building Safety Evaluation Procedures* (ATC 1995).

ATC-20 and ATC-20-1 synthesized the best practices identified from across the globe and were based upon evaluation and assessment approaches from Japan, the International Conference of Building Officials, Kaiser Foundation Health Plan, the Structural Engineering Association of Northern California, the California Governor's Office of Emergency Services (CalOES), and earlier Applied Technology Council (ATC) documents. ATC-20 describes general procedures for building safety evaluation that includes a three-level evaluation process: Rapid; Detailed; and Engineering (see Table 2-1). The objective of each evaluation is a posting classification that clearly communicates the status of the building to the general public and other emergency professionals. ATC-20 utilizes three placard postings: INSPECTED, LIMITED ENTRY, and UNSAFE.

The Rapid Evaluation is normally the first level of evaluation and is designed to quickly (i.e., in 10 to 20 minutes) designate the apparently safe and the obviously unsafe structures. Structures

Table 2-1. ATC-20 building evaluation techniques.

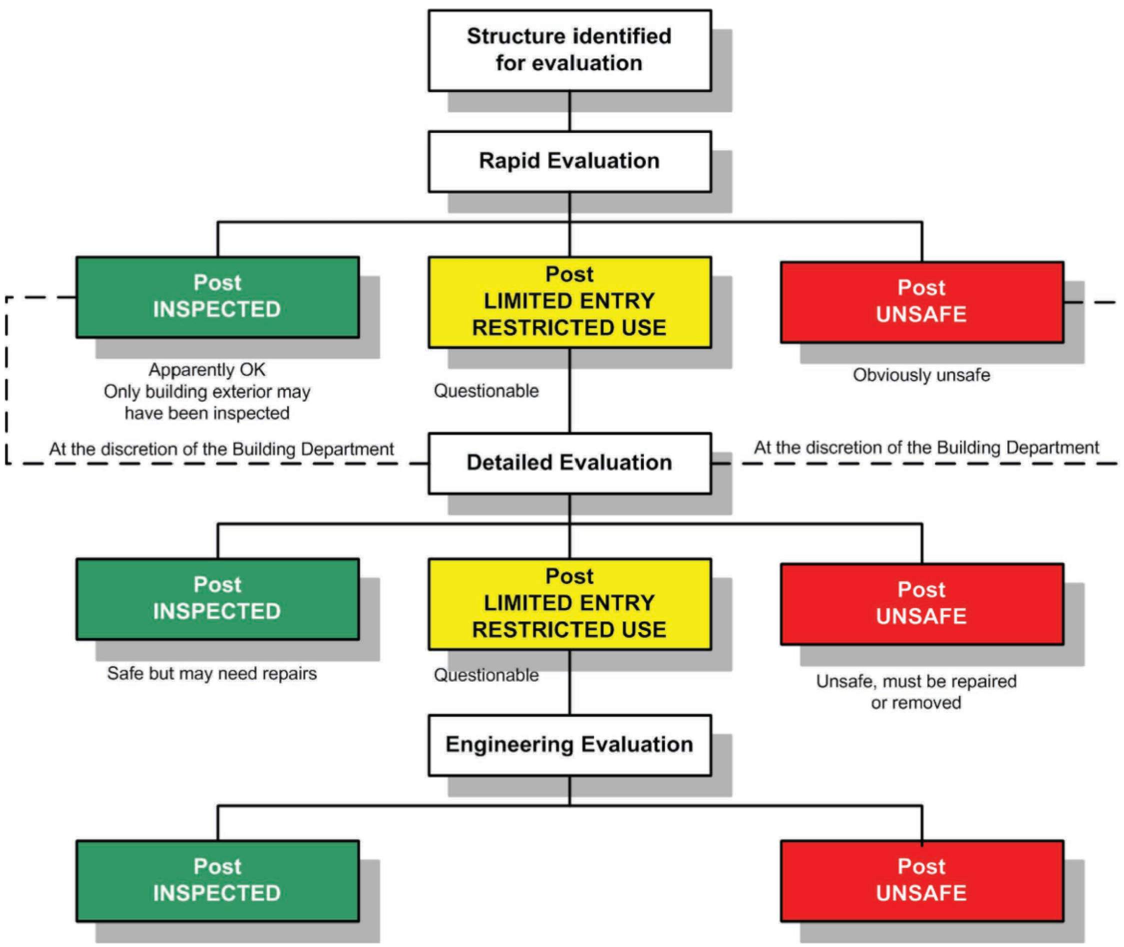
Technique	Required Personnel	Goal	Example Time per Building
Rapid Evaluation	Qualified building inspectors Civil/structural engineers Architects Other individuals deemed qualified by local jurisdiction	Rapid assessment of safety. Used to quickly post obviously unsafe and apparently safe structures, and to identify buildings requiring Detailed Evaluation.	10–20 minutes
Detailed Evaluation	Structural engineers*	Careful visual evaluation of damaged buildings and questionable situations. Used to identify buildings requiring an Engineering Evaluation.	1–4 hours
Engineering Evaluation	Structural engineering consultant*	Detailed engineering investigation of damaged buildings, involving use of construction drawings, damage data, and new structural calculations.	1–7 days or more

*Geotechnical specialists required for assessment of geotechnical hazards
Source: ATC (1989)

that show some signs of damage but are not apparently safe or obviously unsafe are designated for a more detailed visual examination. Basic Rapid Evaluation criteria and inspection procedures are discussed in detail in ATC-20. The Detailed Evaluation is the second evaluation level and requires a more thorough structural inspection (i.e., 1 to 4 hours). The result of this evaluation is either a green INSPECTED placard, a red UNSAFE placard, or a yellow LIMITED ENTRY placard. The posting of a LIMITED ENTRY placard after a Detailed Evaluation means that the building requires the third level of evaluation, the Engineering Evaluation. Engineering Evaluations are performed by consultants requested by the owner of the building. Figure 2-1 describes the evaluation process.

ATC-20 includes detailed discussions of the inspection of various structure types including wood frame, masonry, tilt-up, concrete, and steel frame. These discussions describe typical damage and their likely location and guide the inspector toward an appropriate rating. Furthermore ATC-20 discusses the inspection of geotechnical hazards, non-structural hazards, special issues for essential facilities, human behavior following earthquakes, and field safety.

ATC-20 was published 1 month before the 1989 Loma Prieta earthquake and was used extensively during the recovery efforts. Based on lessons learned during this event as well as the 1994 Northridge and 1995 Kobe earthquakes, an addendum, ATC-20-2, was developed.



Source: CalOES (2013)

Figure 2-1. ATC-20 building evaluation flowchart.

The primary revisions in ATC-20-2 were to the posting placards and the evaluation forms. Most noticeably is that the yellow LIMITED ENTRY placard was changed to RESTRICTED USE. In addition, ATC-20-2 discusses safety assessment management, which includes records management, reconnaissance survey procedures, the removal of goods from buildings with safety restrictions, and demolition considerations. ATC-20-2 also includes information regarding loss value estimations (see Table 2-2) that can be used to help determine the total damage the community actually suffered during the earthquake.

ATC-45 *Field Manual: Safety Evaluation of Buildings After Wind Storms and Floods* builds upon the evaluation procedures developed in the ATC-20 series of documents and applies them to wind and flood hazards. ATC-45 uses the same three-level evaluation approach (i.e., Rapid, Detailed, and Engineering) and the same posting placards (i.e., green INSPECTED, yellow RESTRICTED USE, and red UNSAFE) as ATC-20-2. Furthermore ATC-45 includes guidance on typical damage types and levels as well as an appropriate posting.

2.2.1.2 Highway Structures

Several DOTs have developed hazard-specific guidelines and procedures manuals. The procedures tend to define from two to four response levels that are initiated by the magnitude of the emergency situation. In addition, they describe a two- to four-step evaluation process (e.g., Rapid, Detailed, Engineering as described in ATC-20). Each evaluation step has specific objectives and is initiated by the response levels. The guidelines often include inspection procedures, inspection forms, typical damage photos, training information, and common repair and retrofit options.

Table 2-3 provides a list of assessment and/or coding and marking procedures currently in place by state DOTs obtained via the questionnaire. It is possible that state DOTs not listed may have procedures in place of which the respondents were not aware. Several states (e.g., California and Oregon) are currently developing, updating, or expanding procedures at this time; however, they have not yet publicly released them.

The procedures are typically organized into emergency response plans. In Table 2-3, the plans listed under specific hazards are plans that address only that hazard, while general plans may in some cases refer to many hazards [e.g., Oregon DOT has an emergency operations plan (EOP) that covers major events in general such as earthquake, tsunami, fire, flood, hurricane, or tornado; Pennsylvania DOT (PennDOT) has a damage inspection section in its *Bridge Safety Inspection Manual* that covers extreme events; and Utah DOT has an EOP that covers events such as earthquake, fire, flooding, etc.]. This table reflects that, in general, many DOTs lack assessing, coding, and marking procedures for hazards other than earthquakes. Furthermore, this table highlights the fact that assessment procedures have been developed mainly for bridge structures.

Table 2-2. ATC-20-2 building loss estimation classifications.

Damage State	Damage Factor Range	Central Damage Factor
1—None	0%	0.0%
2—Slight	0–1%	0.5%
3—Light	1–10%	5.0%
4—Moderate	10–30%	20.0%
5—Heavy	30–60%	45.0%
6—Major	60–100%	80.0%
7—Destroyed	100%	100.0%

Source: ATC (1995)

Table 2-3. Assessing, coding, and marking procedures currently in place or being developed by state DOTs.

Procedures	Bridges	Tunnels	Walls	Culverts	Embankments	Overhead Signs
Coding and/or Marking	• Connecticut[A] • Maryland • New York[B] • Ohio[C] • Oregon[D]	• Maryland • New York[B] • Ohio[C]	• Maryland • New York[B]	• Maryland • New York[B] • Ohio[C] • Oregon[D]	• New York[B]	• Colorado • Connecticut[A]
General	• FHWA[E] • Connecticut[A] • Illinois[F] • Maryland • Minnesota[G] • Mississippi[H] • New York[B] • Ohio[I] • Oregon[D] • Pennsylvania[J] • Utah[K] • Washington[L] • Wisconsin[M]	• Oregon[D] • Pennsylvania[J] • Virginia • Wisconsin[M]	• Connecticut[A] • Pennsylvania[J] • Utah[K] • Wisconsin[M]	• Connecticut[A] • Illinois[F] • Maryland • North Dakota • Oregon[D] • Pennsylvania[J] • Utah[K] • Virginia • Wisconsin[M]	• Oregon[D] • Pennsylvania[J] • Utah[K] • Wisconsin[M]	• Connecticut[A] • Florida • Hawaii • North Dakota • Pennsylvania[J] • Utah[K] • Wisconsin[M]
Earthquake	• Arkansas • California • Illinois[N] • Indiana[O] • Iowa • Kentucky[P] • Mississippi[Q] • New York[R] • Washington[S] • Oregon	None	None	• Indiana[O] • Kentucky[P] • Mississippi[Q]	• Indiana[O] • Kentucky[P] • Mississippi[Q]	• Iowa
Tsunami	None	None	None	None	None	None
Tornado	None	None	None	None	None	None
High Winds	None	None	None	None	None	None
Hurricane and Storm Surge	None	None	None	None	None	None
Flooding	• California • Maryland • Ohio[I]	None	None	None	None	None
Fire	• California	None	None	None	None	None

A Connecticut DOT—*Bridge Inspection Manual*: http://www.ct.gov/dot/lib/dot/documents/dpublications/Inspection_Manual_061905.pdf

B New York State DOT (NYSDOT)—*Bridge Inventory Manual*: https://www.dot.ny.gov/divisions/engineering/structures/manuals/bridge-inventory-manual

C Ohio DOT—*Bridge Inventory Coding Guide*: https://www.dot.state.oh.us/Divisions/Engineering/Structures/BridgeManagementSection/StructureInventory/Documents/Bridge_Inventory_Coding_Guide_Revised_2012-01.pdf

D Oregon DOT—*Bridge Inspection Program Manual*: http://www.oregon.gov/ODOT/HWY/BRIDGE/docs/brinspecman2013.pdf

E *Bridge Inspector's Reference Manual*: https://www.fhwa.dot.gov/bridge/nbis.cfm

F Illinois DOT—*Bridge Element Inspection Manual*: http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Bridges/Inspection/Bridge%20Element%20Inspection%20Manual%20REV%2002.2014.pdf

G Minnesota DOT—Bridge Inspection: http://www.dot.state.mn.us/bridge/inspection.html

H Mississippi DOT—*Bridge Safety Inspection Policy and Procedure Manual*: http://mdot.ms.gov/documents/Bridge/Manuals/Bridge%20Safety%20Inspection%20Policy%20and%20Procedures.pdf

I Ohio DOT—Bridge Inspection and Maintenance: http://www.dot.state.oh.us/Divisions/Engineering/Structures/bridge%20operations%20and%20maintenance/Pages/default.aspx

J Pennsylvania DOT (PennDOT)—*Bridge Safety Inspection Manual*: ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB 238.pdf

K Utah DOT—*Bridge Management Manual*, Chapter 5: Emergency Response Plan: http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4321

L Washington State DOT (WSDOT)—*Bridge Inspection Manual*: http://www.wsdot.wa.gov/Publications/Manuals/M36-64.htm

M Wisconsin DOT—*Structures Inspection Manual*: http://on.dot.wi.gov/dtid_bos/extranet/structures/maintenance/index.htm

N Illinois DOT—Earthquake Preparedness, Response and Recovery Plan: http://www.operationsacademy.org/PDF/ListServer/2011/Seismic%20Activity%20in%20New%20Jersey/Attachments/pdfNew%20April%202010%20Earthquake%20Preparedness%20Response%20and%20Recovery%20Plan.pdf

O Indiana DOT—*Handbook for the Post-Earthquake Safety Evaluation of Bridges and Roads*: http://www.cusec.org/capstone14/documents/ttf/INDOT-HANDBOOK.PDF

P Kentucky Transportation Cabinet—*Post-Earthquake Investigation Field Manual for the State of Kentucky*: http://www.ktc.uky.edu/projects/post-earthquake-investigation-field-manual-for-the-state-of-kentucky/

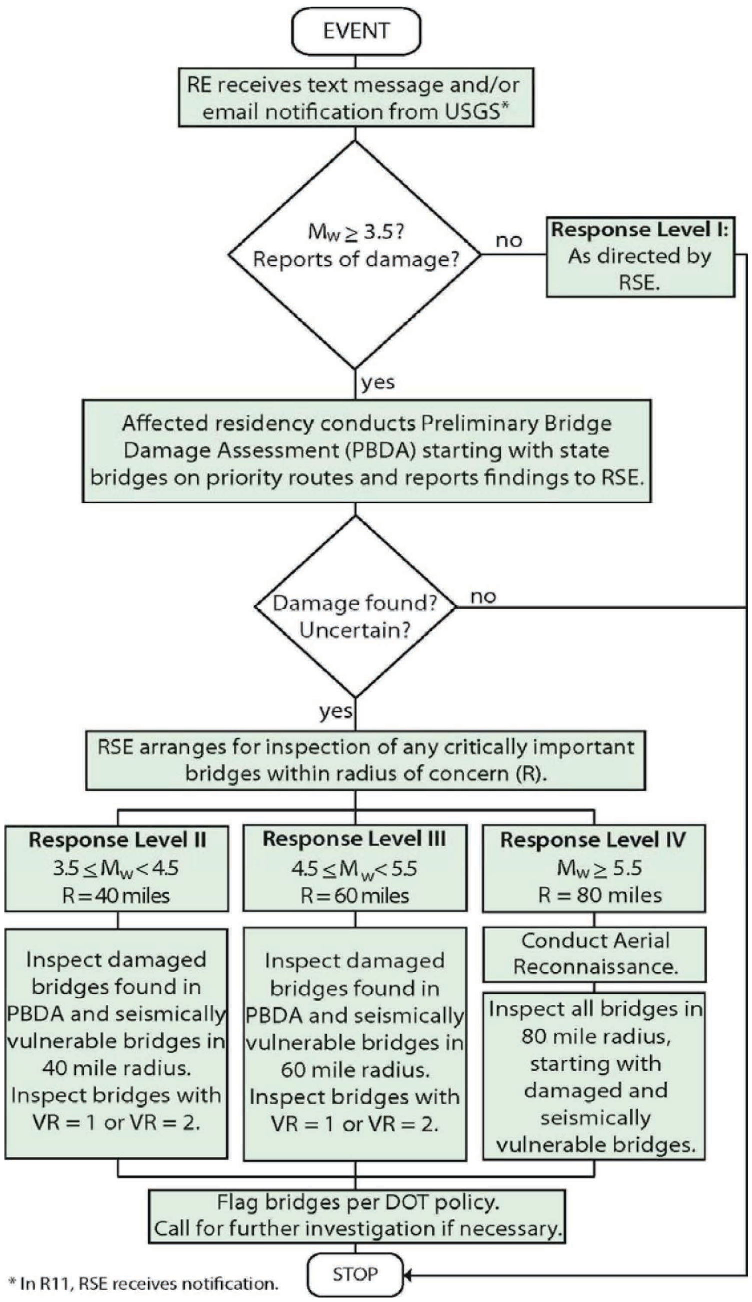
Q Mississippi DOT—Annex E – Earthquake Response Plan: http://mdot.ms.gov/documents/enforcement/emergency_services/CETRP/Annex%20E%20-%20Earthquake%20Response%20Plan.pdf

R NYSDOT—*Post-Earthquake Bridge Inspection Guidelines*: https://www.dot.ny.gov/divisions/engineering/technical-services/trans-r-and-d-repository/C-06-14_Post-Eq%20Final%20Report_October%202010.pdf

S WSDOT—*An Emergency Response Plan for Bridge Management*: http://www.wsdot.wa.gov/research/reports/fullreports/289.1.pdf

Five of the aforementioned guidelines [those developed by the New York State DOT (NYSDOT), Indiana DOT, Washington State DOT (WSDOT), Michigan State Police (MSP), and CalOES] are reviewed in the following paragraphs.

NYSDOT recently developed *Post-earthquake Bridge Inspection Guidelines* (O'Connor 2010). These guidelines include a computer program to help prioritize the inspections based on the distance of the bridge from the epicenter of the earthquake and define four response levels depending on the earthquake magnitude and the distance from the epicenter (see Figure 2-2). In addition, the guidelines utilize four types of evaluation techniques: Aerial Reconnaissance,



Source: O'Connor (2010).

Figure 2-2. Process flowchart for NYSDOT earthquake response plan.

Preliminary Bridge Damage Assessment, Special Post-Earthquake Bridge Inspection, and Further Investigation (see Table 2-4). The guidelines recommend that all personnel subscribe to the U.S. Geological Survey (USGS) Earthquake Notification Service, because this is the trigger for the Emergency Response Plan to be activated in New York State.

Indiana DOT and WSDOT have similar reference documents to NYSDOT for dealing with seismic events (Ramirez et al. 2000, Reed and Wang 1993). The main difference is that the Indiana DOT includes only two evaluation techniques (essentially these are Rapid and Detailed as described in ATC-20) in its document, while the WSDOT uses four (i.e., Levels I, II, and III and Forensic). Furthermore, the WSDOT uses four damage classifications. Three are the same as outlined by ATC-20 and NYSDOT, but WSDOT adds a fourth classification (i.e., UNSAFE-LOW CONFIDENCE) to highlight the evaluators' confidence in the evaluation and structures that require a more detailed evaluation.

The procedures in Michigan are noteworthy because they utilize a web-based incident management system that can provide a color-coded regional status display with damage maps showing both private and public infrastructure (MSP 2013). Section 2.2.3 discusses these visualizations in

Table 2-4. NYSDOT post-earthquake damage evaluation techniques.

	Aerial Reconnaissance (Response Level IV)	Preliminary Bridge Damage Assessment (PBDA)	Special Post-Earthquake Bridge Inspection (SPEBI)	Further Investigation
Objective	Global perspective	Route reconnaissance	Detailed inspection	Special study to address a particular concern
Scope	All structures in affected area	All structures in affected area, starting with priority routes	Site specific	Site specific, as needed
Inspection Method	Helicopter or small fixed-wing aircraft or other "fast" methods	Drive-through with quick stop at each structure	Inspection and special access equipment as needed	Any special equipment that is needed
Personnel	1 or 2 DOT managers in aircraft and technicians as needed; the public	Trained emergency responders	Structural inspection teams	Specialists, e.g., structural, geotechnical, metallurgical
Time Frame	Immediate (within 24 hours)	Immediate (within hours)	Start ASAP (usually within 8 hours) and continue as necessary	Subsequent to SPEBI
Outcome	• Determine the geographic extent of damage • Identify impassible routes and traffic bottlenecks • Locate structures that have major damage or are obviously unsafe • Suggest priority for ground assessments	• Determine the extent and type of damage • Identify/confirm impassible routes and traffic bottlenecks • Close unsafe structures • Code and mark • Recommend SPEBI for damaged or suspect structures • Preliminary damage level estimate	• Code and mark as necessary • Close unsafe structures • Recommendations for restriction, repair, or further investigation • Reopen structures deemed safe that were closed as a precautionary measure during PBDA survey • Damage level estimate	• Code and mark as necessary • Detailed damage analysis • Provide specific recommendations on necessary restrictions and/or repair • Approximate cost estimate for remedial work
Deliverable	Reconnaissance report with maps, photos, and/or video that defines the affected region	PBDA form (one line per structure)	SPEBI Report for each structure and Daily Summary Report	Special engineering report

Source: Based on O'Connor (2010).

more detail. Michigan's emergency response process includes four-color-coded damage classifications and damage assessment forms for both public and private use. The forms are intended to be filled out via the web but can be printed out and filled in by hand if web access is unavailable.

CalOES recognizes that the safety evaluation of buildings and bridges following a significant seismic event will likely overwhelm the capabilities of local and state officials. Thus CalOES developed the Safety Assessment Program (SAP) to build a large network of trained volunteers that can be called upon to assist local government and state employees in the evaluation of structures. SAP has its origins in the response to the 1971 San Fernando earthquake and the current version of the training manual is largely based on ATC-20. In addition to buildings, the SAP evaluator training manual includes guidelines on the assessment of lifeline systems and facilities, which includes bridges, roads, and highways (CalOES 2013). The CalOES SAP evaluator training manual states that lifeline systems and facilities are considered "critical components of a community's infrastructure," thus "only Detailed Evaluations will be performed."

The CalOES document includes forms for the evaluation of bridges. The SAP bridge assessment form was used during the 1989 Loma Prieta earthquake and after the 2008 hurricane season in Haiti. The CalOES SAP manual states that these forms will be revised and improved upon further use. The objective of these forms is to provide sufficient information to classify a system as either safe to return to service (i.e., green INSPECTED), can be returned to service with some restrictions (i.e., yellow RESTRICTED USE), or must be taken out of service until repaired (i.e., red UNSAFE). Despite using classifications similar to the placards in ATC-20, the manual states that infrastructure is not physically posted, rather the jurisdiction is alerted for immediate action.

2.2.2 Inspection Manuals

This section will describe inspection manuals utilized by DOTs. The first subsection will describe manuals for inspections that are meant for non-emergency situations, such as routine inspections. The second subsection will describe generalized manuals for emergency situations. The third subsection will describe methods in place that are specific to a hazard, material, or structure.

2.2.2.1 Non-Emergency Situations

There are many documents related to the inspection of bridges and highway structures available in the literature that are primarily for non-emergency situations. These documents will not be discussed in depth, but rather their importance as potential references for future projects is acknowledged. Note that the intent of this project was not to replace the current routine inspection procedures in place.

The National Bridge Inspection Standards (NBIS) establish requirements for inspection procedures, frequency of inspection, a bridge inspection organization, qualifications of personnel, inspection reports, and preparation and maintenance of bridge inventory records. The NBIS apply to all structures defined as highway bridges located on or over all public roads and set minimum requirements. States may develop more restrictive requirements if they choose. The NBIS describe seven different types of bridge inspections. The most relevant to this project is the Damage Inspection, which is defined as an unscheduled inspection to assess structural damage resulting from environmental factors or human actions. Based on the questionnaire results, 80% of DOTs indicated they use the NBIS for highway bridge inspections, while 20% indicated that they use another system. Of the latter 20%, about half of those indicated they used a combination of NBIS and a state system, while nearly the other half indicated their own state system was used.

The *Bridge Inspector's Reference Manual* is a comprehensive manual on programs, procedures, and techniques for inspecting and evaluating a variety of in-service highway bridges (Ryan et al. 2012). Several FHWA training courses have been developed based on the *Bridge Inspector's Reference Manual*. The manual includes an extensive bibliography as well as a chapter on Advanced Inspection methods.

The AASHTO *Manual for Bridge Evaluation* (MBE) was developed to assist bridge owners by establishing inspection procedures and evaluation practices that meet the NBIS (AASHTO 2011). The MBE includes a section on damage inspection and also describes bridge posting requirements. This manual includes many useful bridge evaluation references (Browne et al. 2010, Shanafelt and Horn 1984, Imbsen et al. 1987, Richardson and Davis 2001).

Many states have their own inspection/evaluation manuals (Illinois DOT 2014; Mississippi DOT 2012a), but they often refer to the AASHTO MBE. In response to the questionnaire, many DOTs indicated that, for other highway structures (tunnels, walls, embankments, culverts, or overhead signs), they have written assessment procedures in place, including a manual or training material (44%), or informal methods in place (22%), as shown in Figure 2-3(a). Two percent indicated that they had pictorial guides/references.

2.2.2.2 Emergency Situations

In contrast to the availability of inspection materials for non-emergency situations, 40% of DOTs responding to the questionnaire indicated that there were no methods in place for emergency situations, as shown in Figure 2-3(b). Only 22% of the respondents indicated that a manual or training material was in place, and 30% of the respondents indicated that informal methods were in place.

The structure type is generally considered in these procedures (although to a larger extent in routine inspections); about 83% of respondents consider it for routine inspections compared

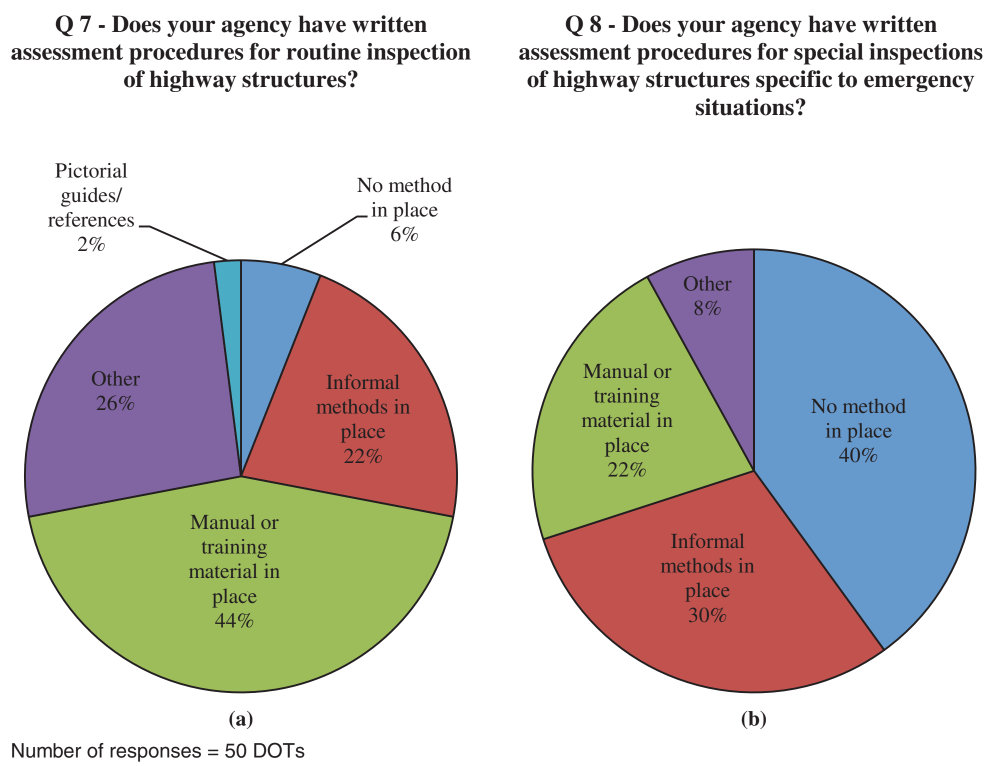


Figure 2-3. Questionnaire result—assessment procedures in place for other structures in both (a) routine and (b) emergency situations.

Table 2-5. Inspection routines based on structure, hazard, and traffic type.

	Routine		Emergency		Difference
	Yes	No	Yes	No	
Q 7a/8a - Is the inspection different based on structure type?	82.6%	17.4%	64.5%	35.5%	18.1%
Q 7b/8b - Is the inspection different based on hazard type?	37.0%	63.0%	51.6%	48.4%	−14.7%
Q 7c/8c - Is the inspection different based on traffic levels?	21.3%	78.7%	33.3%	66.7%	−12.1%

Number of responses = 46 DOTs for 7a/b/c, 31 DOTs for 8a/b/c.

to about 65% for emergency conditions (Table 2-5). Approximately 52% of respondents indicated that the emergency inspection procedures consider the different hazard types. However, in general, traffic levels are generally not considered in routine or emergency inspections, with only about 21% of the respondents indicating that they were considered in routine inspections and about 33% in emergency inspections.

Respondents were asked about procedures in place for prioritization of inspections for responding to emergency situations. Field personnel reports (70%), predetermined lists or lifeline routes (58%), and preliminary geospatial analyses (42%) are all commonly used. Respondents also indicated that technologies such as ShakeCast [California DOT (Caltrans), WSDOT], aerial surveys (Tennessee DOT), and vulnerability assessments (Nevada DOT) are used for earthquake priority response. Florida and Utah DOTs indicated they use a combination of a predetermined list of critical structures and field personnel reports. Virginia DOT determines priority by a predetermined list: major structures for earthquakes and areas most affected for flooding. Michigan DOT determines the priority for inspections as required by state emergency operations centers.

Respondents generally indicated (90%) that the inspection procedures for emergency conditions consider the skill level/training of inspectors. An inspector has authority to close a bridge in 94% of respondents' jurisdictions. The other respondents indicated that an engineer had the authority.

Respondents identified primary challenges (Table 2-6) for inspections by ranking a list (1 most important, 10 least important). The top three challenges identified are travel to the structure, access to the structure, and insufficient number of qualified inspectors.

Table 2-6. Ranked order of challenges to inspectors identified by respondents.

Q 11 – What are the most significant challenges your agency faces to properly assessing structures in emergency conditions?						
Rank	**Response**	**Average Rank**	**Max. Rank**	**Min. Rank**	**Median Rank**	**Standard Deviation**
1	Travel to the structure	2.81	1	9	2	2.07
2	Access to the structure	3.25	1	8	2	2.14
3	Insufficient number of qualified/trained inspectors	3.79	1	9	4	2.29
4	Communications	4.67	1	9	4	2.63
5	Limitations on technology for assessment	5.79	2	9	6	1.97
6	Coordination with other agencies	5.81	1	9	6	2.28
7	Lack of published procedures	5.94	1	10	6	2.45
8	Insufficient resources	6.35	1	10	7	2.56
9	Insufficient training	6.73	2	9	7	1.61
10	Other	9.85	4	10	10	0.87

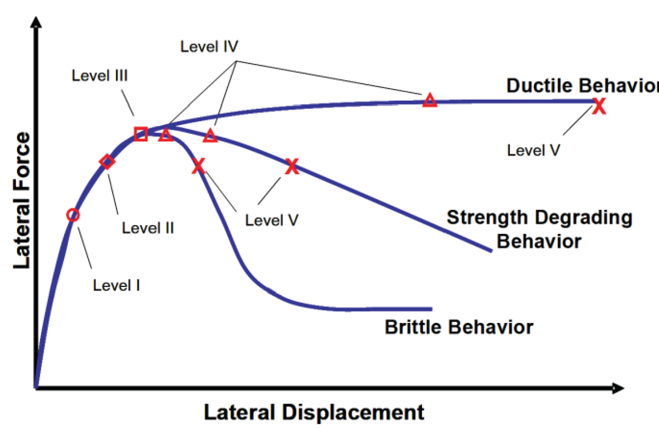
Number of responses = 48 DOTs.

2.2.2.3 Hazards/Material/Bridge Element Specific

There are many documents that provide focused evaluation procedures for specific hazards and/or structure types. These include *The Evaluation of Earthquake Damaged Concrete and Masonry Wall Buildings* (ATC 1998a, ATC 1998b), "Post-earthquake Inspection Manual for RC Bridge Columns" (Veletzos et al. 2008), and *A Guide to F-scale Damage Assessment* [of Wood Frame Houses] (National Oceanic and Atmospheric Administration/National Weather Service 2003). Some documents are very comprehensive and focused on non-emergency situations but are relevant to this project's objectives such as the *Underwater Inspection of Bridges* (Collins et al. 1989) and the inspection guide in *Effects of Fire Damage on the Structural Properties of Steel Bridge Elements* (Brandt et al. 2011). PennDOT funded a series of projects that studied the corrosion and repair of pre-stressed girders, which included a study of various assessment techniques that included six different non-destructive testing (NDT) techniques (Harries et al. 2009, Jones et al. 2010, Naito and Warncke 2010, Naito et al. 2010). Some documents may be relevant for pre-event planning and offer risk-based algorithms to prioritize assessment and inspection (Heintz 2012, Laman and Guyer 2010). A few documents aim to standardize assessment practices (Geotechnical Extreme Events Reconnaissance 2011, Massarra 2012). Other documents describe the performance of specific structure types during past events (Youd and Beckman 1996).

Optical technologies (e.g., lidar and satellite imagery) can provide regional damage assessment. Remotely sensed data are important to hazard investigation and damage assessment because these data can be remotely collected safely during disaster conditions (Olsen et al. 2013). Even in cases in which no previous data are available, optical remote sensing techniques provide high-resolution data, enabling more rapid damage assessment at a regional scale than many alternative methods. Collection of remotely sensed data prior to disasters can serve as baselines for future damage assessment, in addition to being useful for evaluating existing and future hazards. Finally, remotely sensed data, when processed, provide geographic information system (GIS) products for engineers, scientists, and planners to explore and study, without having to travel physically to the site.

Caltrans developed an inspection and assessment procedure for earthquake damage to reinforced concrete bridge elements (Veletzos et al. 2008). This approach is unique because it assesses the remaining displacement capacity. This is achieved by using five damage levels and classifying the expected response using three performance curves: ductile, strength degrading, and brittle (see Figure 2-4). The procedure includes a flowchart to identify the appropriate performance curve and a visual catalog of damage to determine the appropriate damage level. The damage



Source: Veletzos et al. (2008).

Figure 2-4. Performance curves of reinforced concrete bridge column.

on all columns of the bridge can be plotted on the appropriate damage curves to visualize the remaining capacity of the full structure (see Figure 2-4).

2.2.3 Collection, Reporting, and Visualizing Assessment Information

There are numerous documents that describe methods for collecting, reporting, and visualizing assessment information. The majority use paper assessment forms (ATC 1989, CalOES 2013), while some utilize digital forms (McLane and Porter 2008, MSP 2013) which allow for rapid integration into an incident management system for regional visualizations (see Figures 2-5, 2-6, and 2-7). The inspection/assessment forms can be hazard specific and can vary by state and by the evaluation technique (i.e., Rapid or Detailed in ATC-20).

2.2.4 Critiques and Suggested Improvements to Current Assessment Methods

Several recent studies attempt to improve upon current assessment methods considering recent disaster events. New Zealand researchers modeled their post-earthquake assessment procedures after ATC-20 (Department of Building and Housing 2012). Thus, the recent earthquakes in New Zealand provide an opportunity to improve upon the existing ATC-20 documents. Several papers in the literature discuss lessons learned from the Canterbury, New Zealand, events and suggest improvements to current assessment procedures and the ATC-20 documents

Type of Disaster / Survey Date:	Flooding* / Severe Storm; 10/21/12	**County:**	Any County, MI
Street Name or Location:	Maple Street	**Local Jurisdiction:**	Any City / Township / Village, MI
Team Conducting Survey:	Smith / Jones / Thompson	**Damage Type (Public or Private):**	Private

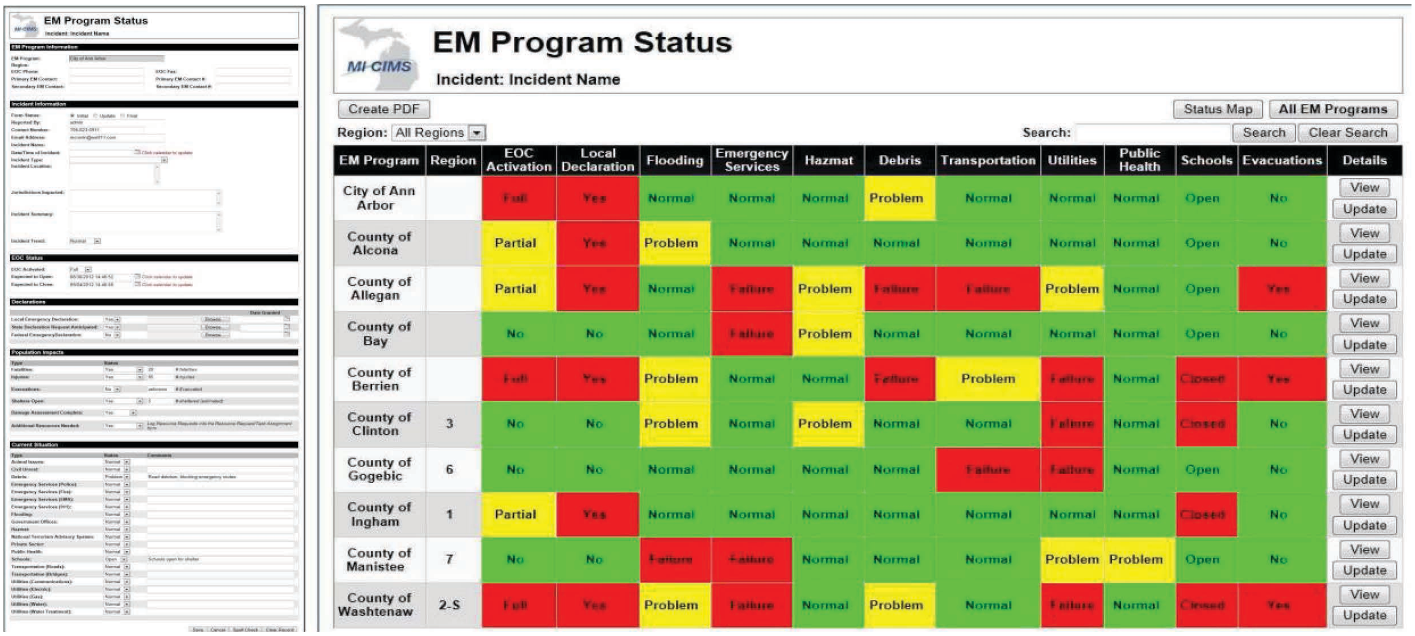
Address or General Location	Degree of Damage				Type of Structure	Flood Level in Feet: B=basement F=first floor		Description of Damage (Include cost estimate for public facility damage. Include insurance coverage estimate for damage, if available / applicable. An alternative would be to use a simple alphabetic code for insurance coverage – e.g., N = no insurance; U = under insured; I = fully insured.)	Latitude / Longitude (if possible)
	0	1	2	3		B	F		
100 Block: 105 Maple Street		X			S	1.5	---	1.5 feet of water in basement only; has flood insurance (100%)	N42°57'19 / W085°07'45
108 Maple Street		X			S	1.5	---	1.5 feet of water in basement only; no flood insurance (0%)	N42°57'24 / W085°08'02
111 Maple Street			X		S	---	2.5	Water below door knob; basement inundated; no flood insurance (0%)	N42°57'19 / W085°07'58
114 Maple Street				X	M	---	1.5	1.5 feet of water above floor level – destroyed; has flood insurance (100%)	N42°57'19 / W085°08'58
200 Block: 207 Maple Street				X	S	---	---	Completely gone – destroyed; has insurance (100%)	N42°57'16 / W085°08'14
212 Maple Street				X	S	---	---	Front walls still standing; everything else gone; has insurance (100%)	N42°57'14 / W085°08'14
217 Maple Street				X	S	---	---	Roof / outside walls gone – destroyed; has insurance (100%)	N42°57'13 / W085°08'18
239 Maple Street	X				S	---	---	Downed tree damaged porch corner only; insurance info not available	N42°57'11 / W085°08'21
*Note: Short duration flooding – less than 8 hours									
TOTALS:	1	2	1	4				NOTE: After the survey is completed, this worksheet should be **RETAINED** locally for reference and follow-up by federal and state officials. It is recommended that **SEPARATE WORKSHEETS** be used, wherever possible, to survey public and private damage.	

Damage Classification	Currently Habitable / Useable?	Approximate % of Damage	Flood Depth: Traditional At-Site Built Structure	Flood Depth: Manufactured (Mobile) Home
0 – AFFECTED	Yes; without repairs	Minimal damage; mostly cosmetic	Less than 3 inches of water in occupied or required room	Minor access problems; no damage affecting habitability
1 – MINOR DAMAGE	No; repairs likely to take less than 30 days	< 50% damaged; damaged windows and doors	Three (3) to 18 inches of water in occupied or required room	Water line is below the floor system; skirting or HVAC may be impacted
2 – MAJOR DAMAGE	No; repairs likely to take more than 30 days	$\geq$ 50% damaged; involves structural features affecting strength / safety	Eighteen (18) inches or more of water on the first floor or water that covers electrical outlets	Water impacts the floor system (to include belly board insulation, ductwork, subflooring); water line of up to 12 inches within the living area
3 – DESTROYED	No; permanently uninhabitable	100%; repair costs exceed structure's value	Damage from flood makes structure permanently uninhabitable	Water line higher than 12 inches within the living area; structure frame is bent, twisted, or otherwise compromised; interior compromised by contamination that clean-up is not feasible

TYPE OF STRUCTURE: **S – Single Family Home** (Primary Residence); **M – Manufactured (Mobile) Home** (Primary Residence); **A – Apartment / Rental Unit** (Rental Residence); **V – Vacation Home / Cottage** (Secondary Residence); **B – Business** (For-Profit Organization); **NPO – Non-Profit Organization** (Not-For-Profit Organization); **P – Public Facility** (Also indicate the type of structure by name)

Source: MSP (2013).

Figure 2-5. Michigan's damage survey worksheet for public infrastructure (MSP 2013).


EM Program Status

MI-CIMS

Incident: Incident Name

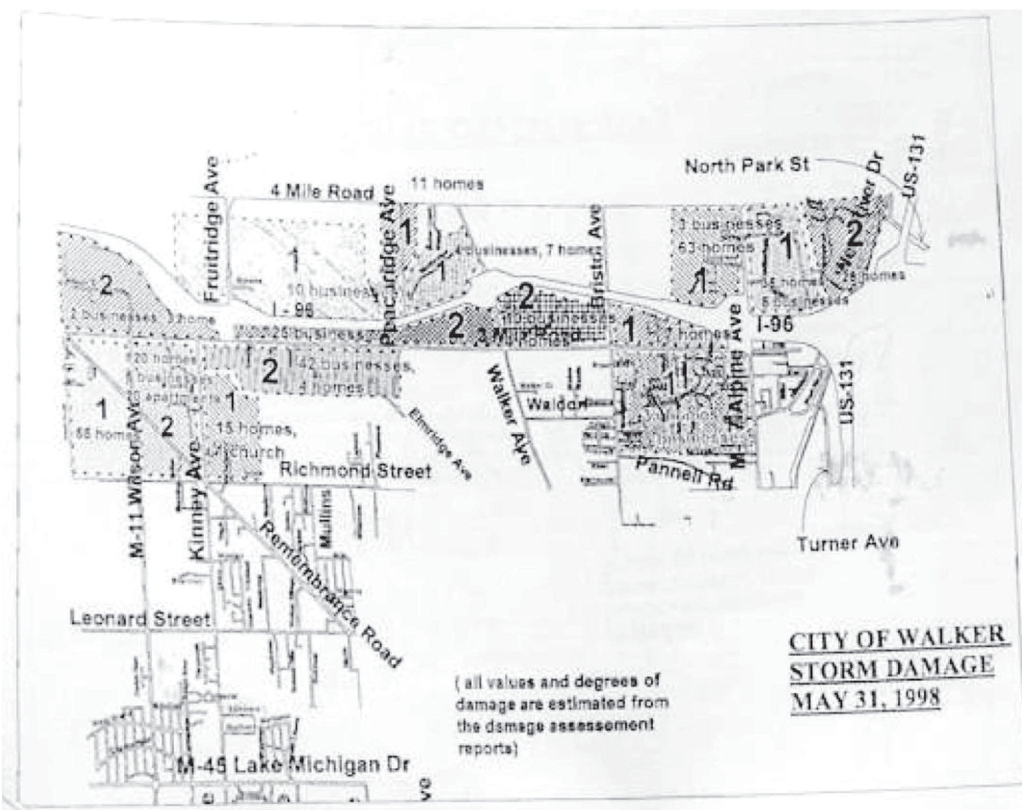
Create PDF | Status Map | All EM Programs

Region: All Regions | Search: | Search | Clear Search

EM Program	Region	EOC Activation	Local Declaration	Flooding	Emergency Services	Hazmat	Debris	Transportation	Utilities	Public Health	Schools	Evacuations	Details
City of Ann Arbor		Full	Yes	Normal	Normal	Normal	Problem	Normal	Normal	Normal	Open	No	View Update
County of Alcona		Partial	Yes	Problem	Normal	Normal	Normal	Normal	Normal	Normal	Open	No	View Update
County of Allegan		Partial	Yes	Normal	Failure	Problem	Failure	Failure	Problem	Normal	Open	Yes	View Update
County of Bay		No	No	Normal	Failure	Problem	Normal	Normal	Normal	Normal	Open	No	View Update
County of Berrien		Full	Yes	Problem	Normal	Normal	Failure	Problem	Failure	Normal	Closed	Yes	View Update
County of Clinton	3	No	No	Problem	Normal	Problem	Normal	Normal	Failure	Normal	Closed	No	View Update
County of Gogebic	6	No	No	Normal	Normal	Normal	Normal	Failure	Failure	Normal	Open	No	View Update
County of Ingham	1	Partial	Yes	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Closed	No	View Update
County of Manistee	7	No	No	Failure	Failure	Normal	Normal	Normal	Problem	Problem	Open	No	View Update
County of Washtenaw	2-S	Full	Yes	Problem	Failure	Normal	Problem	Normal	Failure	Normal	Closed	Yes	View Update

Source: MSP (2013).

Figure 2-6. Screenshot of Michigan's emergency management program showing the status view.



Source: MSP (2013).

Figure 2-7. Example of Michigan's damage assessment map.

(Galloway et al. 2012, Lizundia et al. 2012, Wood et al. 2012). Although many of these are mainly applicable to building structures, they are important considerations for prioritizing inspection routes of highway structures or can be adapted to a highway structure assessment process. The following subsections summarize key findings of the papers.

2.2.4.1 Assessment Process

The following recommendations were made for the New Zealand assessment process:

- The objective of a Level One Rapid Assessment (roughly equivalent to the Rapid Evaluation in ATC-20) should be to determine whether a building is immediately considered dangerous or needs a Level Two Rapid Assessment (roughly equivalent to the Detailed Evaluation in ATC-20).
- A new Interim Use Evaluation should be defined, which would be carried out by the owner's engineer to establish suitability for re-occupation. It is recommended that this would be essentially the same as a Level Two Rapid Assessment, unless the primary vertical or lateral load resisting systems cannot be identified. In this case, further research would be required to identify the primary structural systems in order to establish the extent and significance of damage observed. Guidance on this process has been developed and published for the Greater Christchurch region by the Department of Building and Housing (Department of Building and Housing 2012).
- Triage should be used to gain an overview of the damage, identify collapse-vulnerable buildings, ensure people are not trapped in any of the buildings, and inform urban search and rescue teams.
- Indicator structures should be identified. Following a large earthquake, many buildings become damaged and are susceptible to additional damage from aftershocks. Some aftershocks may be strong enough to damage previously undamaged buildings. An important decision officials must make is when to require the re-inspection of previously inspected buildings. If an indicator building showed new damage after an aftershock, similar buildings nearby that likely experienced the shaking could then be re-examined for safety. This can also be combined with strong motion instrumentation reports to assist decision makers.

2.2.4.2 Technology Utilization

The following recommendations were made regarding New Zealand utilization of technology to support assessing, coding, and marking:

- Development of a Structure Database: The primary objective of the approach is to gather data on the expected earthquake performance of existing buildings. Summary information for each building could then be provided to assessment teams to inform the rapid building safety evaluations being carried out. In particular, identification of the expected vulnerabilities is considered to be of great benefit when carrying out a rapid visual assessment of damage as these vulnerabilities may not be identifiable without reference to building plans and details.
- Targeted Safety and Evaluation Operations: These are specialized task forces or operations to address sections of the city or issues of the community, rather than the block-by-block method that has often been used in other cities.
- Use of Internet and Social Media for Information Updates: The Christchurch City Council made relatively extensive use of the Internet and social media to provide near-real-time updates to the public on the response and recovery process of the region. This included maps showing the specific zones within the cordoned areas and planned dates for these area cordons to be lifted, and maps that showed areas of higher risk from buildings that could potentially collapse in a strong aftershock.

The use of Internet and social media (crowdsourcing) in disaster response as recommended by New Zealand researchers is one example of how, for present and future disaster response,

Table 2-7. Key obstacles in effective disaster response.

Identified Requirement	Brief Description of Obstacle
Communication and collaboration support	Difficulties in knowledge sharing.
	Inability to access information and the lack of standardization, collaboration, coordination, and communication.
Provision of real-time data to field personnel	First responders' needs for information access and sharing are not well supported and are often disconnected from both the information systems and databases central to effective homeland security.
Visual data capture	Although different types of disasters call for different types of response, most situations can be improved by having visual images and other remotely sensed data available.
On-site building assessment marking	Building marks are not visible because of re-marking/smoke/debris on site and are updated at Incident Command Center after 8 to 12 hours through its established work cycles.
Multiple connectivity options	Existing terrestrial links can easily saturate and collapse at the time of disasters. For instance, after the 9/11 attacks, cellular phones did not work because of the destruction of antennae systems.

Source: Peña-Mora et al. (2008).

modern information technologies should be incorporated to assist in the assessing, coding, and marking of damaged structures. Several of these approaches that utilize IT are discussed in the following paragraphs.

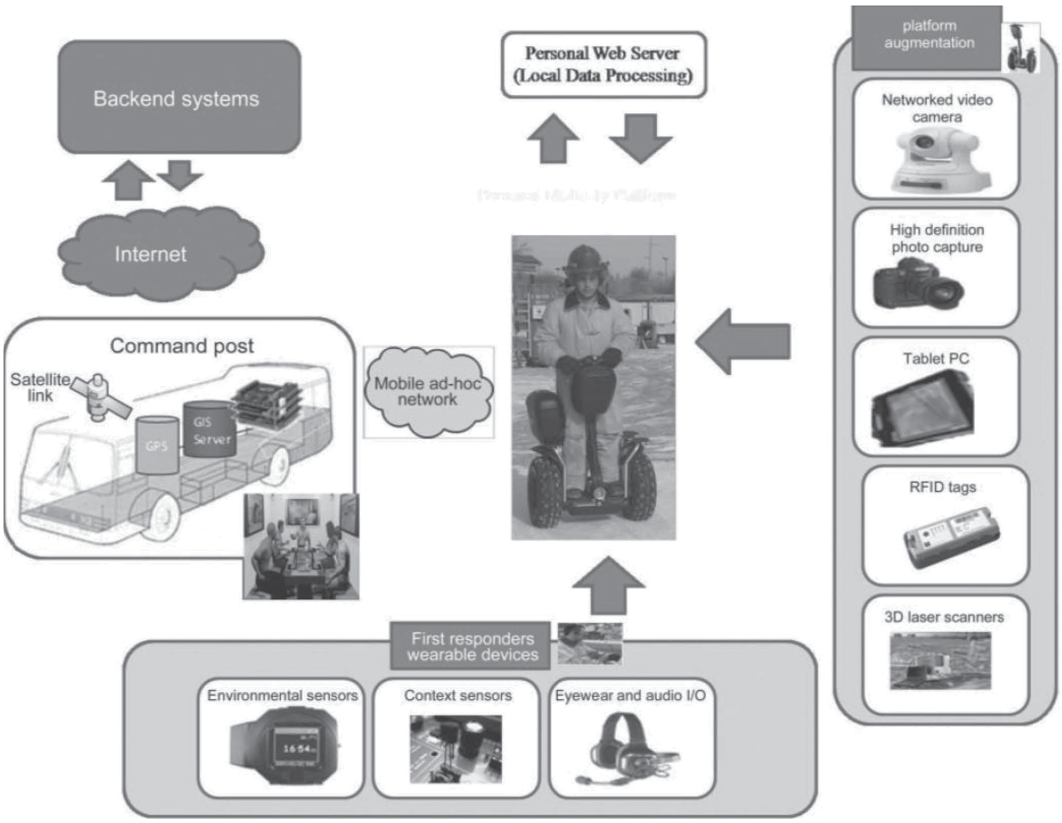
ATC-67 developed a smartphone app [ROVER (Rapid Observation of Vulnerability and Estimation of Risk)] that uses Federal Emergency Management Agency (FEMA)-154 procedures for rapid visual screening of buildings for potential seismic hazards and ATC-20 for post-earthquake tagging of buildings (McLane and Porter 2008). This app is integrated with USGS real-time earthquake monitoring software (ShakeCast) and FEMA multi-hazard damage and loss estimation software (Hazus-MH) (FEMA 2006). ROVER has been successfully tested by the Los Angeles Unified School District, the Utah Seismic Safety Commission, and others.

Peña-Mora et al. (2008) reviewed the role of civil engineers in disaster response with a focus on existing building assessment and marking systems and highlighted various limitations of existing approaches (Table 2-7). They discussed a mobile IT-based collaborative framework to facilitate a coordinated disaster response and recovery operation. This framework enables engineers to assess building damage better and to make this information available to personnel more quickly and easily within the disaster area and thereby improve disaster response. The deployed architecture is composed of various components including various sensing, scanning, and tagging devices for structural assessment, a field engineer's mobility and information support platform, and GIS-based resource optimization (see Figure 2-8). As mobile- and cloud-computing technologies continue to advance, the command post concept as shown in Figure 2-8 may become outdated; sophisticated data processing and analytics can be realized through collaborative distributed mobile-computing systems rather than a centralized command post (Chen et al. 2013).

2.3 Coding and Marking Procedures

During emergency events, it is important for first responders, safety personnel, inspectors, and the traveling public to have and be able to rely on a common method to code and mark highway structures. For this report, the following definitions are intended:

- **Coding**—The process of using a shortened notation or series of code to indicate the status of a structure, its components and elements, and other parameters associated with it.



Source: Peña-Mora et al. (2008).

Figure 2-8. The deployed system architecture.

- **Marking**—The process of applying an identifiable mark to the structure to inform others of its condition. This can be done physically or digitally. The physical marking of a structure is sometimes referred to as "posting."

Today, a consistent, well-established methodology for accomplishing these critical tasks for highway structures in emergency situations does not exist. A review of the literature reveals, in general, very little published information on coding and marking systems at either the federal, state, or local level for highway structures both here in the United States or internationally. One of the practical reasons for this is the challenge inherent in the need for any coding and marking system intended for the general public to be visible and of value to someone driving at highway speeds.

2.3.1 Coding and Marking of Highway Structures

Notably, the FHWA provides courses in bridge inspection under non-emergency conditions. Part of that training involves the use of a detailed coding system (FHWA 1995) that in effect provides the data elements for the National Bridge Inventory (NBI) database. Since all of the trained bridge inspectors in the United States are required to use this system, there may be an opportunity to use part of it, particularly for the more detailed inspections after an emergency event. Pennsylvania (Laning and Bankert 2008), Ohio (Ohio DOT 2012), and New York (NYSDOT 2006) have published similar manuals for their inspector training and reference.

New York uses an electronic reporting system to populate its bridge inventory database. There are more than 20 codes including bridge identification, structural details, safety and utility,

inspection responsibility, and load rating, for example. Within each major category, the detail codes are defined. For example, under safety and utility there are approximately 10 codes to characterize the type of guard rail terminus.

WSDOT has a reference document for dealing with seismic events entitled *An Emergency Response Plan for Bridge Management* (Reed and Wang 1993). Inspection forms were developed to support a three-stage inspection process and office procedures were developed for emergency response. A computer database that makes use of the WSDOT's seismic database was used to develop the plan. Workshops involving the WSDOT, the Division of Emergency Management, and the Department of Community Development were recommended. Research (Ranf et al. 2007) was also conducted at the University of Washington to improve the prioritization of bridge inspections by including not only the distance from the epicenter, but also the age of the bridge.

The Indiana DOT in its *Handbook for the Post-earthquake Safety Evaluation of Bridges and Roads* (Ramirez et al. 2000) describes the use of ribbons by inspectors to communicate the condition of the bridge post inspection. These appear to be for internal use only. The system specifies the use of a red ribbon to indicate the bridge should be closed; yellow if it requires a more detailed inspection; and green if it is safe to use. The ribbons with the initials of the inspector are to be attached to the bridge sign post. If the bridge is unsafe to use, a request for barricades should be made to the proper group.

NCHRP Report 525: Surface Transportation Security, Volume 16: A Guide to Emergency Response Planning at State Transportation Agencies (Wallace et al. 2010) is designed to help executive management and emergency response planners at state transportation agencies as they and their local and regional counterparts assess their respective emergency response plans and identify areas needing improvement so as to be in synchronization with the all-hazards context of the National Incident Management System (NIMS). The report does not specifically address the issues of coding and marking, but it is clear that any system will have to be compatible with the emergency transportation operations for each state.

To reduce the impact from traffic incidents, the FHWA has developed a traffic incident management process and training program for first responders (FHWA 2012). This training program could be a source of valuable information for handling emergency events.

A team of U.S. tunnel professionals performed a scan of best practices in Europe in 2005 and presented key findings in a report entitled, *Underground Transportation Systems in Europe: Safety, Operations, and Emergency Response* (Ernst et al. 2006). The U.S. tunnel engineering community relies on National Fire Protection Association (NFPA) Standards 130 and 502. The AASHTO Subcommittee on Bridges and Structures has formed T-20, the Technical Committee on Tunnels to take the lead on tunnel safety during emergency situations. They found that members of the general public are in effect their own first responders when they find themselves in an emergency. To aid the general public with a safe response, software is being used in Europe in conjunction with video to automate emergency procedures. A one-step procedure is recommended to reduce the chance for human error during an emergency.

Only 30% of respondents to the questionnaire indicated that they have a manual or training material on guidelines for coding and marking of highway structures during emergency situations, as shown in Figure 2-9. While 24% indicated that informal procedures are in place within their DOT, 34% indicated that no method is in place and 12% indicated that they were not aware of any within their agency.

With respect to marking of structures during emergency inspections, 32% of respondents always mark, 10% often mark, 16% sometimes mark, 12% rarely mark, and 22% never mark; 8% were not sure (Figure 2-10). Those that do mark the structure indicated that the marking is typically done in a report (58%) or entered into a database (36%), rather than physically on the

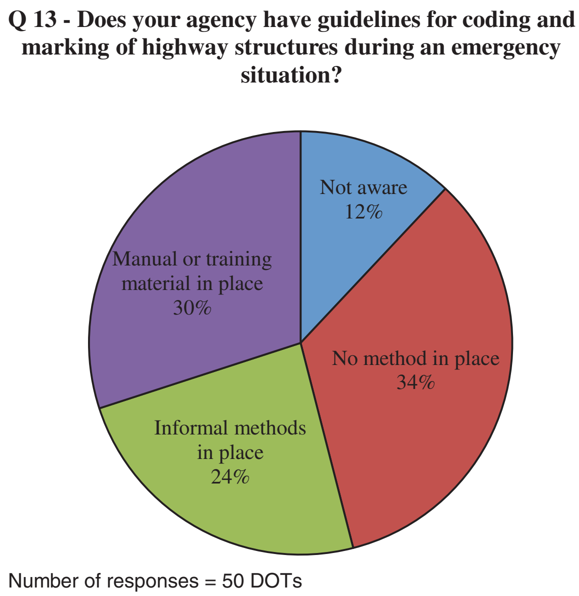


Figure 2-9. Availability of guidelines for coding and marking during emergency situations.

structure. Other methods of marking included spray paint (18%), posting via the web or other digital media (18%), and yellow caution tape (85%). Thirty-four percent of respondents use some other technique for coding and marking of structures, including the following:

- Colored lumber crayon in an obvious location
- Colored tape or ribbon (red, yellow, and green)
- Structures tagging sticker

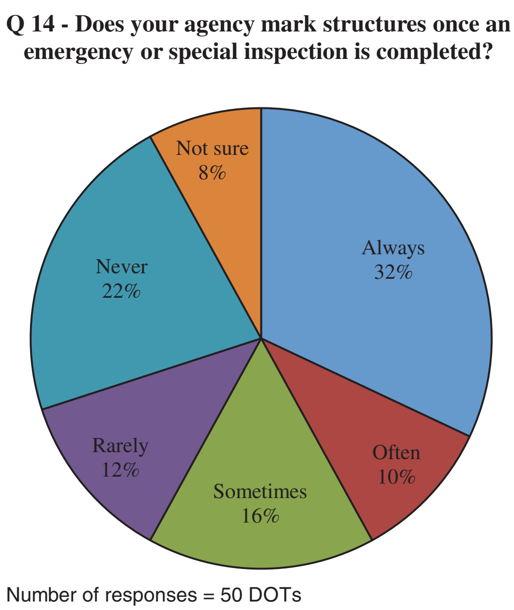


Figure 2-10. Frequency of marking following emergency or special inspections.

- Mississippi DOT's procedure from Annex E of its Comprehensive Emergency Transportation Response Plan (page E-22) based on earthquakes
- Barricades, detour signs, and traffic control devices for bridges required to be closed

2.3.2 Relevant Coding and Marking Practices for Buildings

Most of the remaining literature comes from other emergency management scenarios such as the coding and marking of buildings post-earthquake disasters or, in the case of fire events, from NFPA standards. The latter includes NFPA 130, *Standard for Fixed Guideway Transit and Passenger Rail Systems*, and NFPA 502, *Standard for Road Tunnels, Bridges and Other Limited Access Highways* (NFPA 2014a, 2014b).

"Building Assessment During Disaster Response and Recovery" (Peña-Mora et al. 2008) reviews the role of civil engineers in disaster response with a focus on building assessment and marking. It presents a mobile IT-based collaborative framework to facilitate a coordinated disaster response and recovery operation that includes the use of radio-frequency identification tags and GIS database support. Peña-Mora et al. developed a scoring system to determine which structures will receive operational priority based on the highest probability of success in finding and rescuing live victims. Buildings with the highest scores receive attention first. A similar approach could be applied to highway structures based on their importance to the transportation network and their likely resilience to damage.

The paper discusses the importance of having a standard building assessment and marking system to communicate the building's stability and suitability for use to all concerned personnel. The paper identifies three systems: the National Urban Search and Rescue Response System, which utilizes fluorescent orange spray paint to apply the markings; the International Search and Rescue Response System; and the ATC system, which is for recovery only. The ATC-20 protocol became the de facto standard after being used in response to the attacks of 9/11. The ATC system has three levels—Rapid, Detailed, and Engineering—for the assessments. Green, yellow, and red placards indicate INSPECTED (no restrictions on use), LIMITED USE, and UNSAFE, respectively. Peña-Mora et al. note that, unfortunately, different systems can be used by agencies that are part of the same disaster response, creating significant problems for the teams.

CalOES recently published Version 12 of the *Safety Assessment Program Evaluator Student Manual* (CalOES 2013). This document provides a detailed overview of the Safety Assessment Program as part of the training for SAP evaluators. This program is based on the use of ATC-20-2. It discusses earthquakes, windstorms, floods, fires, and explosions. The program provides for the use of placards to communicate the condition of structures, excluding highways and bridges. The program includes buildings as well as what it refers to as lifeline systems and facilities, which includes airports, bridges, roads and highways, and more.

Duly authorized representatives of a jurisdiction are the only persons who can officially post the placards. Formally adopted placards will have the jurisdictional seal on them and will have a reference to the adoption ordinance. In California there is liability protection for the inspectors and a local jurisdiction would not be liable for workman's compensation if they deputize an inspector.

The current placard system in use in California is ATC-20-2 (ATC 1995). Green, yellow, and red indicate INSPECTED, RESTRICTED, and UNSAFE, respectively. Standard forms are provided to support each level of inspection and marking. California also uses ATC-20-2 for lifeline structures such as bridges and roads/highways. The forms use a ranking of 0 to 6 to code the observed damage. Placards are not used to mark bridges or roads/highways as they are too small for motorists to see. Barricades are the recommended method for restricting access to unsafe structures.

2.3.3 Critiques and Suggested Improvements to Current Coding and Marking Methods

As described earlier, several recent studies attempt to improve upon current coding and marking methods considering recent disaster events. Much of the previously cited literature provides recommendations for coding and marking (termed "placard placement") from lessons learned from the Canterbury, New Zealand, events and suggests improvements to current assessment procedures and the ATC-20 documents (Galloway et al. 2012, Lizundia et al. 2012, Wood et al. 2012). Although many of these are mainly applicable to building structures, they are important considerations for prioritizing inspection routes of highway structures or can be adapted to a highway structure assessment process. The following recommendations were made for placard placement:

- Only suitably experienced structural engineers should be permitted to issue placards (although they may be teamed up with building control officials, etc.).
- There should be a roaming auditor to ensure consistency between assessments carried out by different teams and to identify teams that may not display the required engineering judgment.
- Should an engineer be unable to determine the lateral load resisting system, the building should receive a yellow placard, regardless of the absence of apparent structural damage.
- A minor change to the placard colors is proposed to ensure the public reads the detail of the placards. Using red, yellow, and white would remove the visual correlation between green and go/safe.
- The placards should include a clear distinction as to whether they are based on a Level One or Two assessment.
- The only possible outcome of a Level One Rapid Assessment should be either a red (UNSAFE) placard or a new (perhaps white) placard noting that the building has been visited, but that it requires a further Level Two assessment. Yellow or green placards should not be outcomes of a Level One Rapid Assessment.
- Usability categories should be introduced. Usability categories were used for some assessments in Christchurch as part of the Level Two Rapid Assessment to provide an additional level of information to building occupants, managers, and owners. For the INSPECTED (green) posting, the usability categories were G1 (occupiable, no immediate further action required) and G2 (occupiable, repairs required). For the RESTRICTED USE (yellow) posting, the categories were Y1 (short-term entry) and Y2 (no entry to parts until repaired or demolished). For the UNSAFE (red) posting, the categories were R1 (significant damage, repairs or strengthening possible); R2 (severe damage, demolition likely), and R3 (at risk from adjacent premises or from ground failure).

2.3.4 Coding and Marking Conclusions

There is very little published information on the topics of coding and marking of highway structures during emergency events. There is a well-established system of codes for routine bridge inspections, but those were designed for a different purpose and their required level of detail is not suitable for the majority of emergency responders.

There may be an opportunity to make use of some of the procedures developed by the NFPA and/or ATC although they were not intended for the specific purpose of this project.

The use of a three-level system to communicate with the general public that the condition is safe, restricted, or unsafe using green, yellow, and red, respectively, would seem to be the most valuable methodology to consider in the development of the proposed guidelines. However, if there is a need to communicate with the public at highway speed, this approach may not be practical.

For emergency responders, a more technical methodology could be implemented that makes use of the well-established bridge inspection coding system, at least for the more detailed inspections. If the communication system could be relied upon to support access to the Internet, then a number of new strategies would become available for communicating with the general public and among the emergency responders.

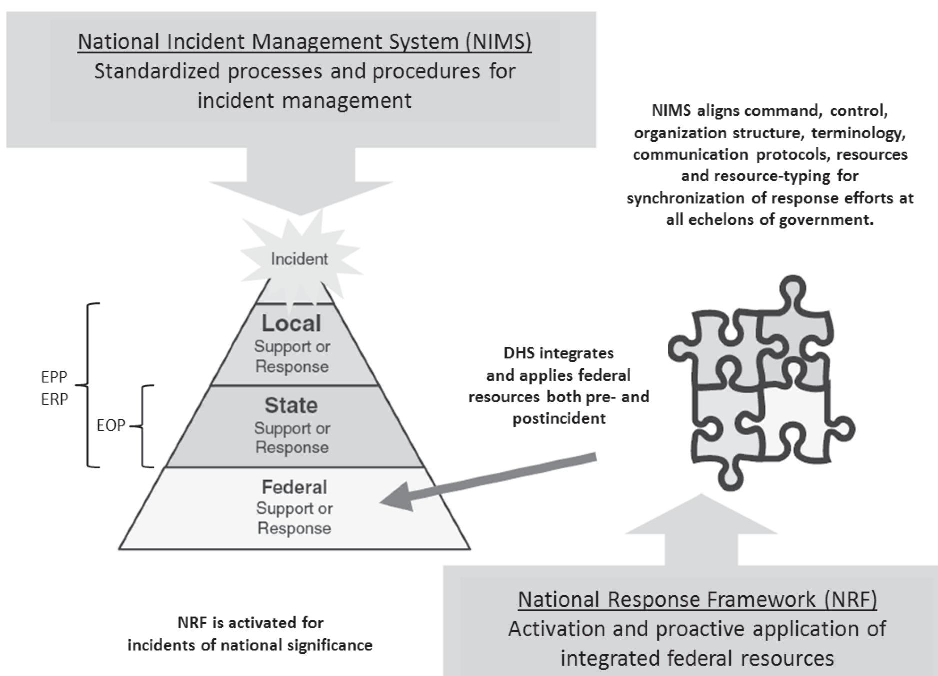
2.4 Emergency Response and Communication

2.4.1 Emergency Management Overview

Emergency management involves preparing for, responding to, and recovering from an emergency or disaster. It is a continuous process by which all levels of government manage hazards in an effort to lessen or avoid the impact of disasters resulting from hazards (FHWA 2014). In general, a government agency can discharge their emergency management responsibilities by taking five interrelated actions: prevention, protection, mitigation, response, and recovery (DHS 2011, FEMA 2010). For the purposes of this project, this section will focus primarily on response and aspects that are important for communicating results of structural inspections.

2.4.1.1 National Incident Management System

The NIMS was produced to standardize the management of emergencies in the United States as well as to implement a system to allow all agencies, departments, and jurisdictions to work together to manage emergencies when necessary (DHS 2008). The NIMS is made up of the following five components: (1) preparedness, (2) communication and information management, (3) resource management, (4) command and management, and (5) ongoing management and maintenance. Figure 2-11 defines the emergency response process based on the NIMS and National Response Framework (NRF).



Source: Based on McCormick Taylor, Inc. (2006).

Figure 2-11. National Response Framework and National Incident Management System.

2.4.1.2 National Response Framework

The NRF is a guide for how our nation conducts national all-hazards incident response that builds upon the NIMS (DHS 2013). It describes structures for achieving nationwide response policy and operational coordination for all types of domestic incidents. Federal assistance available to augment state and local response efforts is formulated under NRF's 15 Emergency Support Functions (ESFs). The most pertinent to this project is ESF #1, Transportation.

ESF #1 provides support by assisting local, state, tribal, territorial, insular area, and federal government entities, voluntary organizations, non-governmental organizations, and the private sector in the management of transportation systems and infrastructure during incidents (DHS 2013). The primary and coordinating agency of ESF #1 is the transportation agency. ESF #1 includes the following functions:

- Monitoring and reporting status of and damage to the transportation system and infrastructure as a result of the incident
- Identifying temporary alternative transportation solutions that can be implemented when systems or infrastructure are damaged, unavailable, or overwhelmed
- Coordinating the restoration and recovery of the transportation systems and infrastructure

2.4.1.3 Emergency Plans

EOPs define the scope of preparedness and emergency management activities necessary. DOTs will either have a stand-alone EOP or the DOT plan will be an annex, appendix, or supplement to the state's EOP. All levels of government—local, tribal, state, and federal—including their division offices—prepare formal EOPs to establish authorities, responsibilities, and procedures on how the organization will operate in response to a disaster or emergency. The federal government has provided many tools to aid state and local agencies in developing EOPs, most notably, the Comprehensive Preparedness Guide (CPG) 101.

The CPG 101 provides guidelines that help planners at all levels of government in their efforts to develop and maintain viable all-hazards, all-threats EOPs (FEMA 2010). FEMA recommends that teams responsible for developing EOPs use CPG 101 to guide their efforts.

Along with EOPs, several state and local agencies will also develop emergency response plans (ERPs) or emergency preparedness plans (EPPs). Based on the questionnaire, 80% of state transportation agencies have an ERP or an EPP on file that is either comprehensive for most hazards (60% of DOTs) or different for each hazard (20% of DOTs), as shown in Figure 2-12(a). To determine the relative maturity of these plans, respondents were asked how long these plans have been in place [Figure 2-12(b)]. Responses were more than 10 years (40%), within 10 years (20%), within the last 5 years (23%), and within the last year (2%). Of the respondents, 15% were not sure of the relative age of these procedures. These responses indicate that many DOTs are taking steps to prepare for potential emergency events and are developing plans. However, given the frequency of occurrence for many events, it is likely that many of these procedures have not been fully tested during actual events. In addition, the relative age of these plans implies that the latest advances in potential assessing, coding, and marking techniques are not incorporated. Hence, future refinements are very likely to be necessary.

Thirty-six respondents (77%) indicated that they were part of the EPP or ERP team. These respondents indicated that there is a strong level of interaction with federal agencies (100%). Of those EPP or ERP respondents, 97% also indicated that they assess structures as part of the EPP/ERP. However, at the local level, 59% of the respondents indicated that the local government does not follow their EPP/ERP. There appears to be minimal coordination with data sharing, which consists predominately of inspection data. Other types indicated by the respondents were emergency needs and information and scour monitoring plan of action.

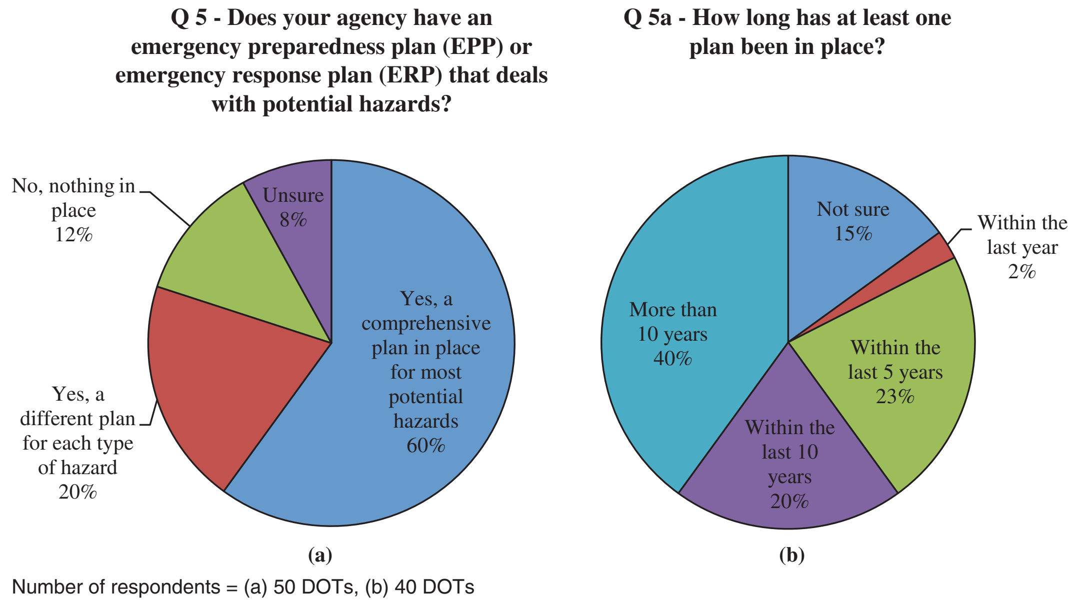


Figure 2-12. Emergency preparedness plans or emergency response plans (a) in place with state DOTs and (b) general length of time that such policies have been in place.

2.4.2 Emergency Preparedness and Response

To identify the relative frequency of hazards facing state DOTs, questionnaire respondents were asked to identify hazards they have faced in the past (Figure 2-13). Flooding (100%), collision (100%), scour (92%), and high winds (90%) were identified as the hazards experienced by most state DOTs. The next most frequently experienced hazards are fire (80%), tornados (66%), and earthquakes (50%). It is interesting to note that the majority of available literature

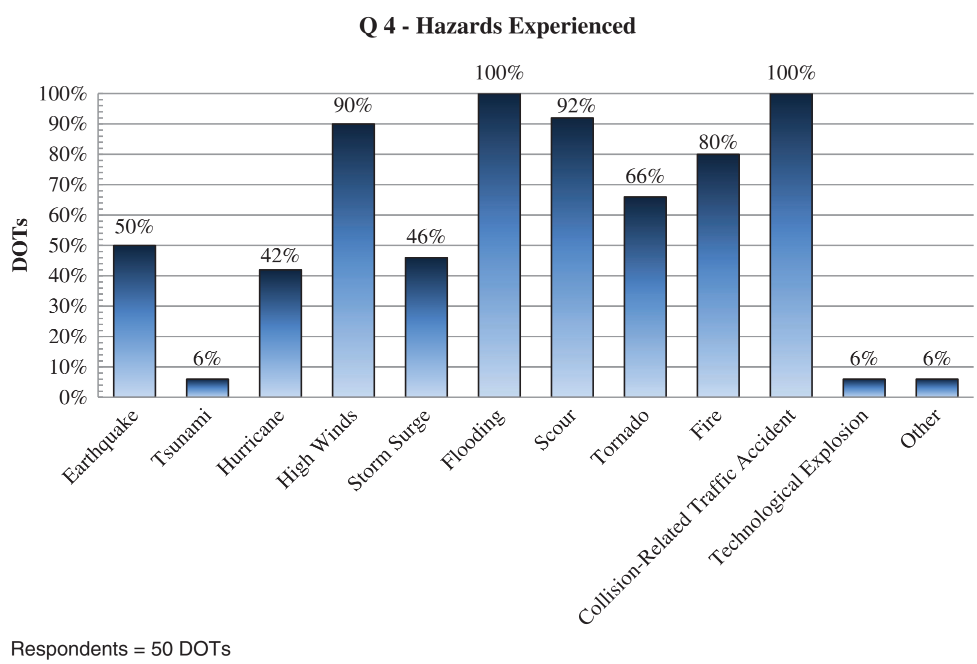


Figure 2-13. Hazards experienced by state DOTs.

and established procedures are related to earthquakes rather than these more common hazards. This is likely because of the widespread nature and higher level of damage expected during an earthquake.

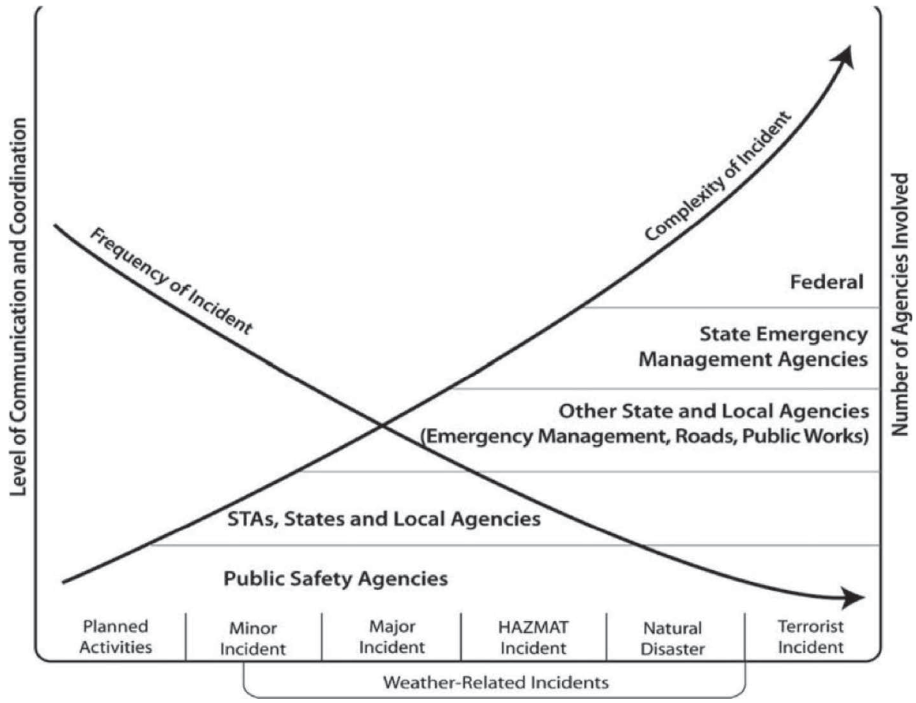
Emergency response begins at the local level and expands to the state and federal level during large disasters where the local government cannot handle the emergency response. The Incident Command System (ICS) is the foundation of emergency management throughout the United States since the inception of the NRF and NIMS (CalOES 2013). Figure 2-14 describes the emergency/disaster declaration process of Michigan. Under ICS, the lowest level of government closest to the disaster is responsible for the management of the emergency response within its jurisdiction. Higher levels of government will then assist in supplying personnel and equipment to aid in the response. Figure 2-15 highlights the relationship between complexity of emergencies and response.

Effective emergency response requires collaboration between multi-jurisdictional agencies. Collaboration is a necessary foundation for dealing with both natural and technological hazards and disasters (Waugh and Streib 2006). Among the possible modes of cooperation, multi-stakeholder cooperation is favored for the management of complex emergency management situations (Smith 2014). Incident communications are facilitated through the development and use of common communications plans and interoperable communications equipment, standards, and

LEVEL	MAJOR ACTIONS
INCIDENT OCCURS	• Initial incident intelligence collected / evaluated / reported by first responders. • Incident Command established in accordance with incident circumstances. • Initial life safety and property protection measures taken. • Key officials notified.
LOCAL EMERGENCY MANAGEMENT PROGRAM JURISDICTION; AFFECTED MSP POST	• Jurisdiction and affected MSP Post submit initial incident information and updates as necessary. • Jurisdiction collects / compiles assessment data per local procedures; field inspection teams collect data; local response agencies provide data through EOC. • Jurisdiction may activate local EOC to monitor situation and coordinate response. • Jurisdiction may declare local "state of emergency" and request state and federal assistance. • Local PIO issues media releases and public advisories per local procedures. • Jurisdiction submits detailed damage assessment information within 72 hours of incident; updates initial incident information as necessary.
MSP/EMHSD	• SEOC may be activated to monitor situation and coordinate response. • MSP/EMHSD District Coordinator assists jurisdiction in assessing and analyzing situation; determines scope and magnitude of event; determines supplemental resource needs. • MRIAT may be activated to provide supplemental assessment assistance. • SEOC Planning Section compiles and analyzes incoming assessment data. • PIOs issue media releases and public advisories per MEMP; JIC may be activated. • Governmental agencies and private relief organizations are alerted to standby status; may provide immediate support to address threats to public health, safety and welfare.
GOVERNOR	• May declare "State of Emergency" or "State of Disaster" under 1976 PA 390, as amended; state assistance rendered to supplement local efforts. • May activate MEMAC / EMAC if appropriate. • May request federal disaster relief assistance, if warranted, through FEMA Region V in Chicago, Illinois.
FEMA	• May provide direct response assistance under National Response Framework (NRF) to save lives, prevent injuries, protect property and the environment. • Conducts Preliminary Damage Assessment (PDA); state and local personnel assist in PDA process. • FEMA Region V reviews and analyzes Governor's request; FEMA Headquarters (Washington, DC) makes recommendation to President.
PRESIDENT	**Issues Declaration:** • Federal disaster assistance programs are activated. **OR** **Denies Declaration:** • Limited federal assistance may still be available. • Governor may provide assistance through State Disaster and Emergency Contingency Fund under 1976 PA 390, as amended, if sufficient state resources (financial and/or materiel) are available.

Source: MSP (2013).

Figure 2-14. Michigan's emergency/disaster declaration process.

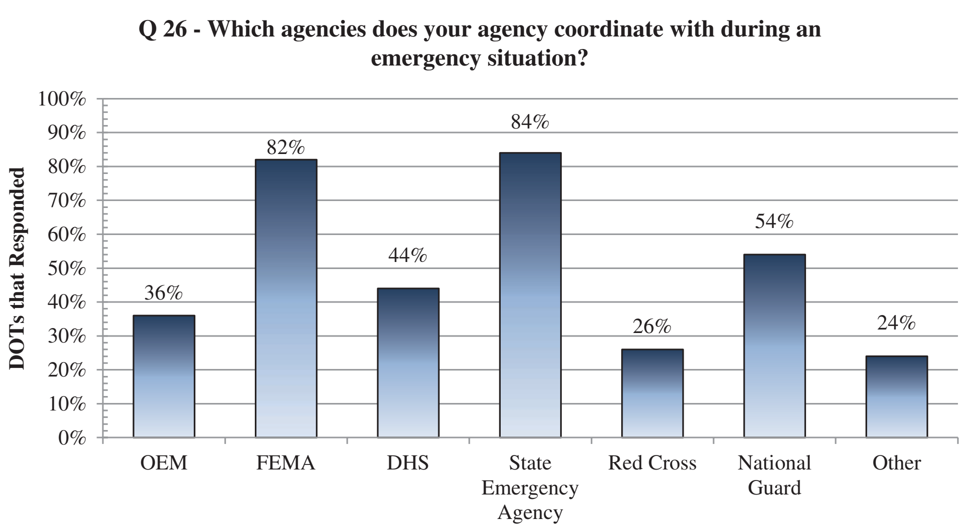


Source: Wallace et al. (2010).

Figure 2-15. The complexity of emergencies and response.

processes. The concepts and principles for effective communication are defined by NIMS as having a common operating picture; interoperability; reliability, scalability, and portability; and resiliency and redundancy. These concepts and principles reinforce the use of a flexible communications and information system in which emergency response personnel can maintain a constant flow of information during an incident (DHS 2008).

From the questionnaire, respondents were asked what agencies they coordinate with during emergency situations (Figure 2-16). State emergency agencies (84%), FEMA (82%), and



Number of respondents = 49 DOTs.

Figure 2-16. Coordination with other emergency agencies.

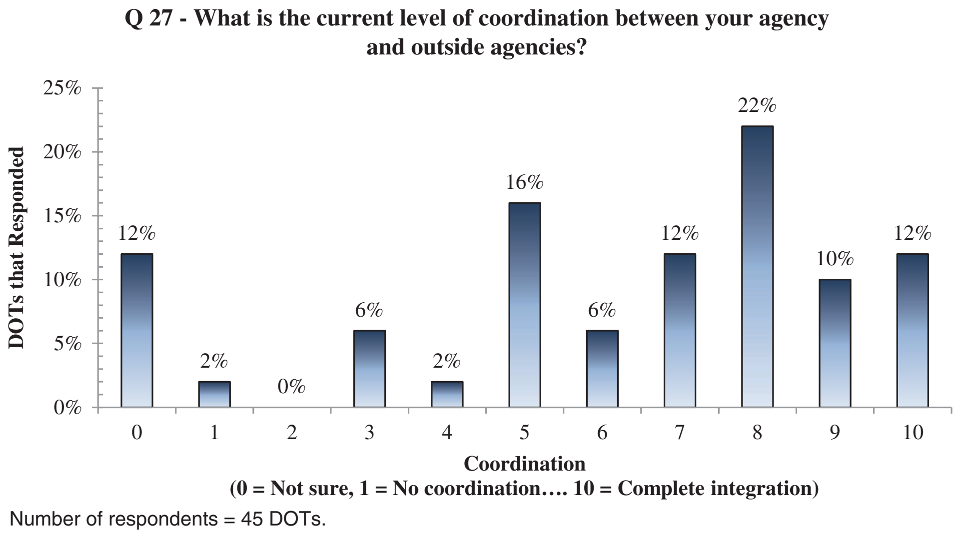


Figure 2-17. Level of coordination with other emergency agencies.

the National Guard (54%) were the primary agencies identified. Many respondents indicated a high level of coordination with other outside agencies (Figure 2-17). Other agencies identified by respondents include the FHWA; U.S. DOT; state police/highway patrol; state health agencies; regional bridge managers; other state DOTs; U.S. Coast Guard; and various other state, county, or local agencies. Respondents indicated that coordination could be most improved by single points of contact, secure websites, or annual in-person meetings (Table 2-8).

While some DOTs (33%) have integrated their asset management and pavement information with emergency response information, most have not done this. However, the majority (60%) indicated that they coordinate with those divisions during emergency events to obtain the necessary data.

2.4.3 Transportation Infrastructure Emergency Response

Rapid assessment of transportation structures is critical following a disaster since they may exist along evacuation routes and can impede evacuation or the movement of emergency personnel and supplies into the disaster zone. States that generally are not affected by natural disasters may have very little preparation for natural disasters and are likely to concentrate on accidental vehicle impacts. Although a vehicle impact creates a similar need for assessment, it is more likely

Table 2-8. Rankings of potential improvements to coordination.

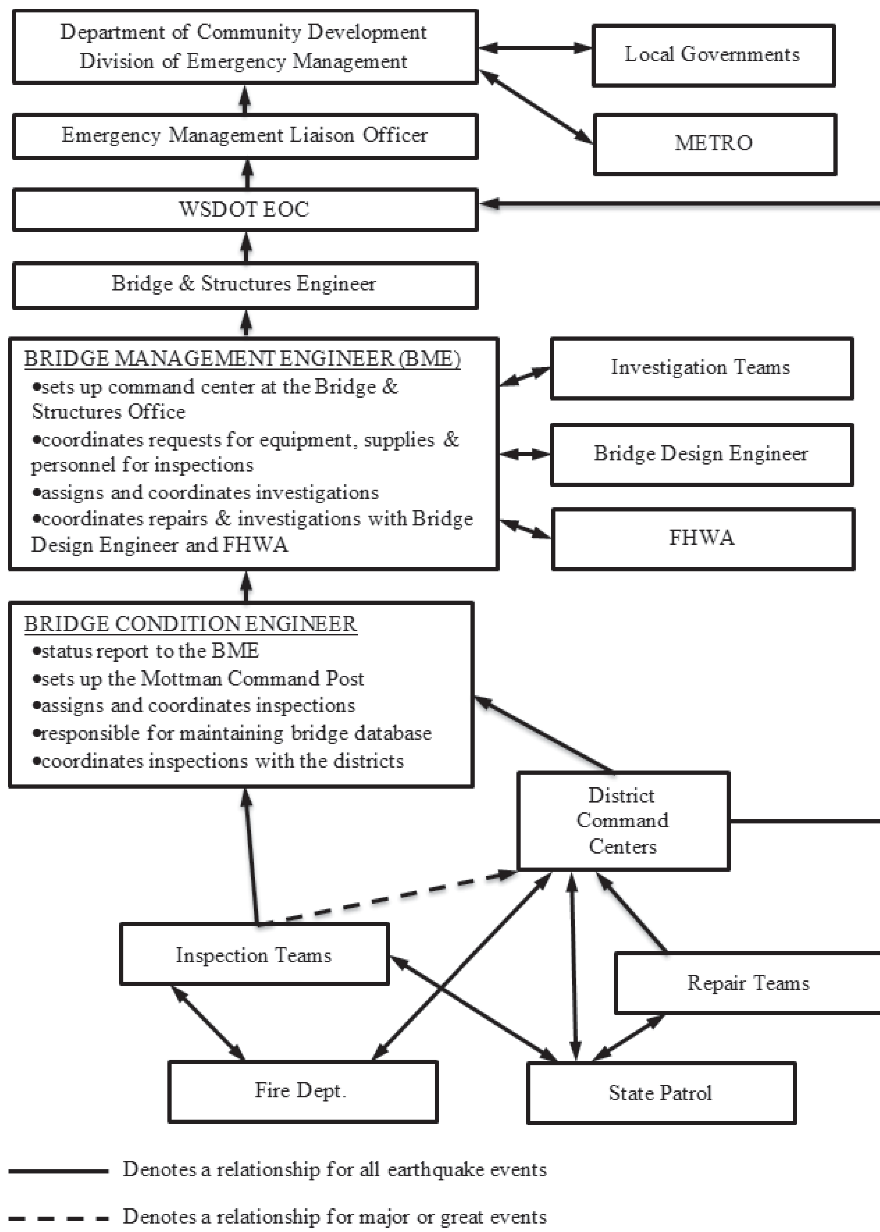
Q 28 – What would improve emergency coordination for your agency?						
Rank	**Response**	**Average Rank**	**Max. Rank**	**Min. Rank**	**Median Rank**	**Standard Deviation**
1	Identify a single point of contact within the DOT	2.75	1	6	2	1.74
2	Create a secure website to manage coordination	2.77	1	5	3	1.31
3	Have an annual face-to-face meeting	2.84	1	5	3	1.16
4	Arrange a regularly scheduled conference call	3.34	1	5	3	1.29
5	Have more mock training events	3.64	1	6	4	1.53
6	Other	5.66	1	6	6	1.20

Number of respondents = 44 DOTs.

to be localized, usually affecting only one structure. Under ESF #1, state DOTs are the primary and coordinating agency for transportation structure assessment.

2.4.3.1 State DOT Response

Within an all-hazards framework, state DOTs have certain transportation-oriented responsibilities. During the response of an emergency, DOTs will activate appropriate plans, procedures, and protocols and mobilize available personnel, equipment, facilities, devices, and information to support emergency response (Wallace et al. 2010). It is also in this stage that state DOTs will begin performing damage assessment responsibilities for affected transportation system elements. This process involves clear lines of communication between numerous teams and agencies as shown in Figure 2-18. Decisions will be made regarding closures, contraflow operations,



Source: Reed and Wang (1993).

Figure 2-18. WSDOT emergency response communication for bridge management.

restrictions, and priority repairs. Damage assessments will continue during the recovery phase (Wallace et al. 2010).

2.4.3.2 Training Volunteer Response

Very-large-extent emergencies are likely to overwhelm the capabilities of local and state officials. In these situations, there is a need for properly trained volunteers to assist with the assessment of structures. Several agencies and associations across the United States have been working to fill this need. These include the CalOES SAP (CalOES 2013) and the Structural Engineering Emergency Response Program (National Council of Structural Engineers Associations 2011). These programs coordinate training and organize volunteers to be called up by local or state emergency management agencies to assist in the safety evaluation of structures during an emergency response when necessary. These volunteer groups currently exist or are being developed in some states (Rhode Island, Massachusetts, California to name a few) but likely do not exist in all states.

2.4.4 Concluding Remarks

Homeland Security Presidential Directives helped shape the foundation of emergency response and communication by establishing national frameworks such as NIMS, NRF, and ICS. These frameworks serve key roles in the development of state EOPs, ERPs, and EPPs. Ultimately, all incident response begins at the local level and progresses toward the state and federal level depending on the complexity of emergency, as shown in Figure 2-15. ESF #1 specifies state DOTs as the primary and coordinating agency for transportation structure assessment. Many states have developed emergency response procedures specific to the assessment of highway structures following an emergency; however, these procedures are likely to differ between states. It is crucial following an emergency for state DOTs to properly and quickly assess, code, and mark the integrity of the transportation system and this process begins with a well-established EOP, ERP, and EPP. CPG 101 is currently the most useful guide in helping planners develop and maintain viable all-hazards and all-threats EOPs. Some good examples of plans set in place by DOTs are Ohio's EOP (Ohio DOT 2013), Mississippi's ERP (Mississippi DOT 2012b), and Wyoming's Multi-Hazard Mitigation Plan (Wyoming DOT 2011).

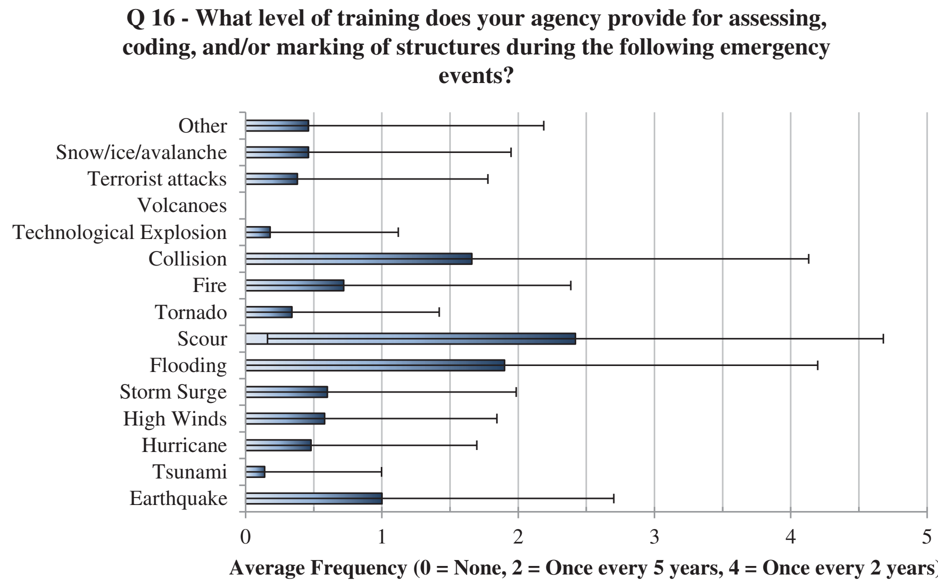
2.5 Training

In the questionnaire, respondents were asked about the level of training available for various types of emergency events (Figure 2-19). Training is most common for scour, flooding, collision, and earthquakes. However, in general, minimal training is completed for other types of hazards, where training is typically not performed frequently, if at all.

When asked how effective various training material was, periodic refresher courses and flipbooks and pocket manuals were given the highest overall rankings (Table 2-9).

2.6 Technology/Data

Similar results are observed in the usage of current technology in routine conditions compared to the priority of technology usage in emergency situations (Figure 2-20). The two primary findings are (1) the order in which digital technologies are currently most often used is largely consistent with the order of priority given to digital technologies during emergency response and (2) smartphones and tablets are given higher priority in emergency events. This implies that the community is keen to use smart mobile technologies for rapid emergency response.



Number of respondents = 44 DOTs.

Figure 2-19. Level of training by state DOTs for hazards. The bars show the standard deviation of the responses for each category.

2.6.1 Data Management

In the questionnaire, respondents were asked how structural assessment data are currently managed within their organization. Eighty percent of respondents indicated data are centrally managed, 14% indicated regionally managed, and 6% indicated individually by department. Most respondents also indicated that they have well-developed and functioning systems in place for asset management and inventory (Figure 2-21). Ninety-six percent of respondents indicated that information regarding structure type and traffic levels was available. Sixty-seven percent of respondents indicated data are tied to geospatial coordinates and 23% indicated that they are tied to another system such as a linear referencing system [Figure 2-22(a)]. Ninety-two percent of respondents indicated that these data are stored in digital databases [Figure 2-22(b)]. Analyzed together, these responses indicate that DOTs are comfortable with digital, geospatial database management and sharing for structural assessment data.

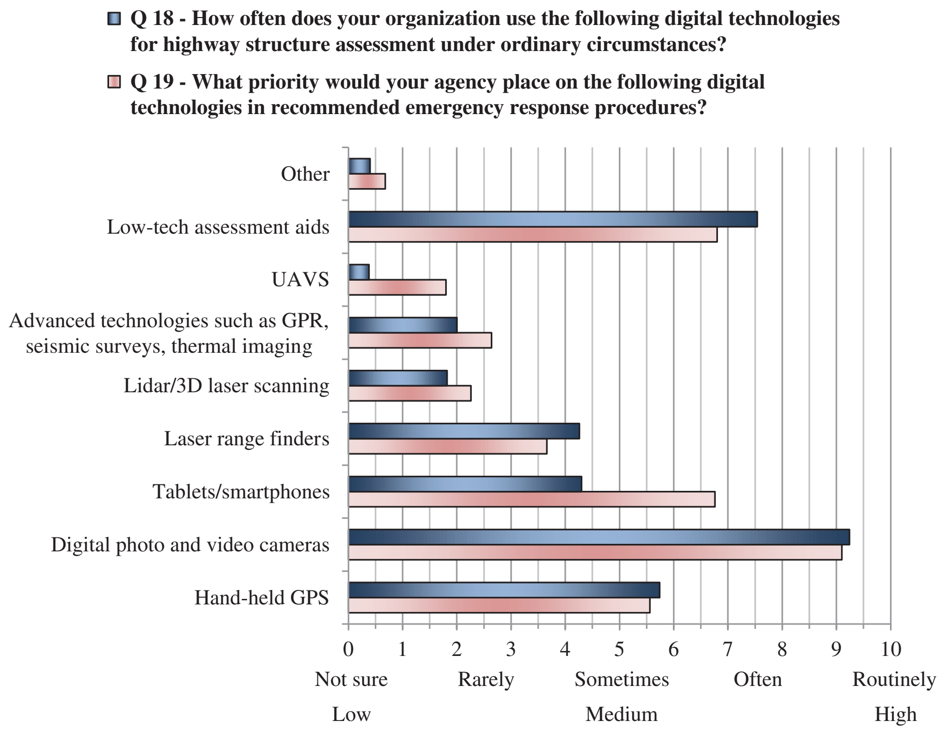
2.6.2 Adoption of New Technologies

Respondents were asked about their agency's experiences with adopting new technologies (Figure 2-23). Thirty percent indicated that their agency tries to stay in the forefront; 38%

Table 2-9. Rankings of training material effectiveness.

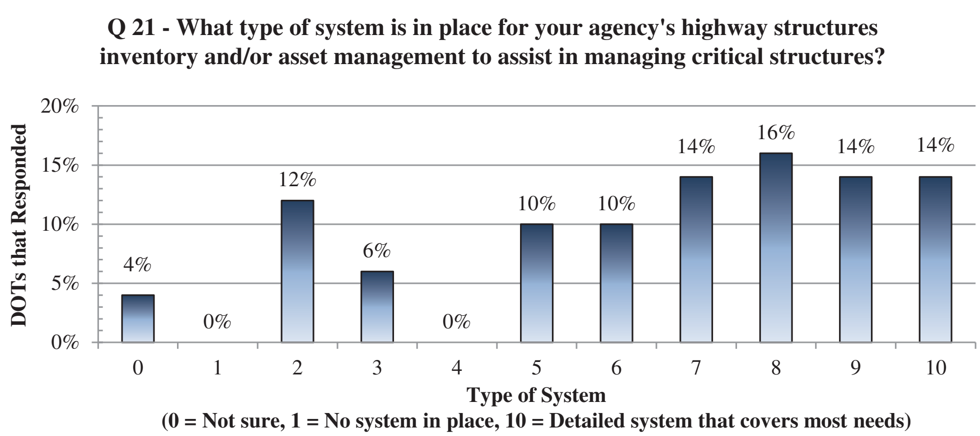
Q 17 – Please order the following list based on your agency's needs to train individuals in the proper emergency response and assessment procedures.						
Rank	**Response**	**Average Rank**	**Max. Rank**	**Min. Rank**	**Median Rank**	**Standard Deviation**
1	Periodic refresher course	1.98	1	4	2	0.99
2	Flip-books and pocket manuals	2.17	1	4	2	0.99
3	Simulations	2.94	1	5	3	1.15
4	E-learning training courses	3.02	1	4	3	1.07
5	Other	4.89	1	5	5	0.60

Number of respondents = 47 DOTs.



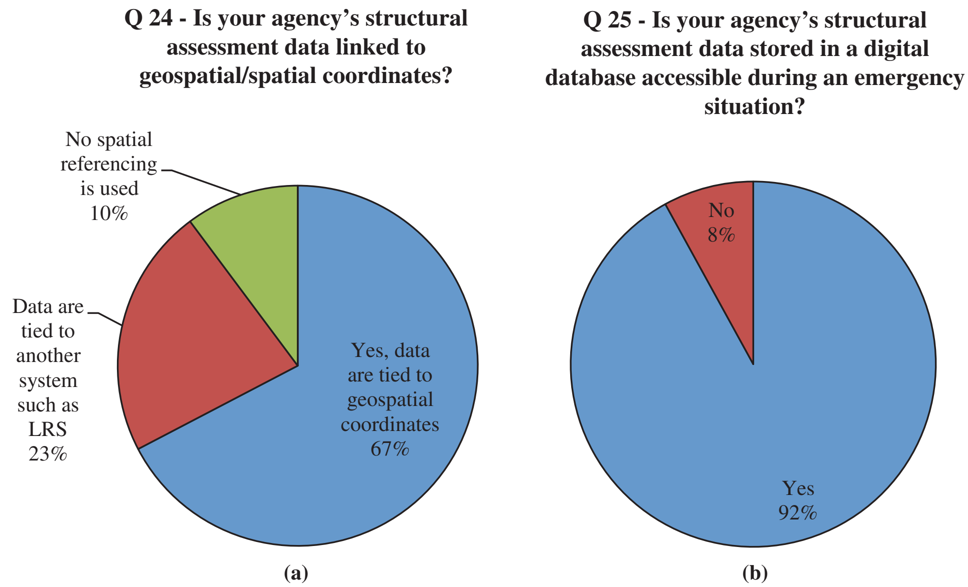
Number of respondents = 48 DOTs.

Figure 2-20. Current technology usage in routine conditions and anticipated technology usage in emergency response.



Number of respondents = 49 DOTs.

Figure 2-21. Inventory and assessment management systems in place for managing critical structures.



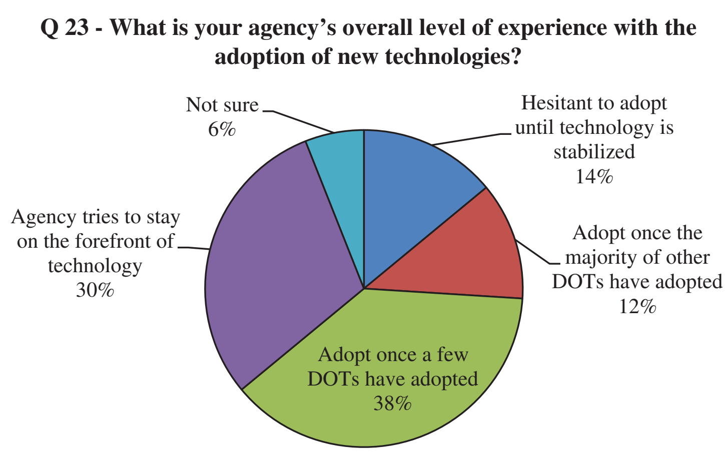
Number of respondents = (a) 49 DOTs, (b) 50 DOTs.
LRS = linear referencing system

Figure 2-22. Structural assessment data (a) tied to geospatial information and (b) stored in digital databases.

indicated that they adopt new technologies once a few other DOTs have adopted; 12% adopt when the majority of other DOTs have adopted; and 14% are hesitant to adopt new technologies. Six percent were not sure. This implies that most agencies (80%) are willing to adopt new technologies when the technology becomes technologically or institutionally mature.

2.7 Guidelines

Respondents indicated that several of the items listed would be of benefit in guidelines (Figure 2-24). In particular, communication and coordination within an agency was given highest priority.



Number of respondents = 50 DOTs.

Figure 2-23. Level of technology adoption by state DOTs.

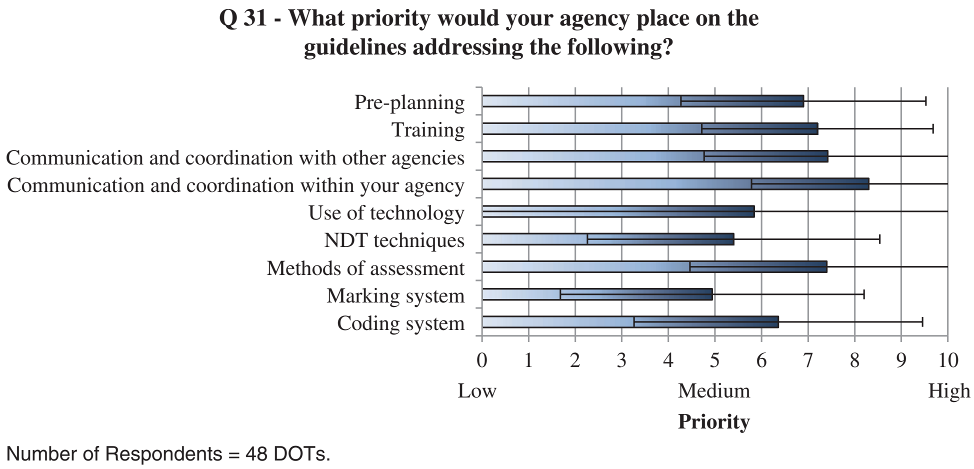


Figure 2-24. Priorities of guidelines. The bars show the standard deviation of the responses for each category.

Respondents also indicated that additional training and increased number of inspectors were the most important needs identified by their agencies to improve structural assessment, coding, and marking procedures in emergency situations (Table 2-10).

2.8 Background Summary

This phase of the project resulted in the documentation of detailed background information and a solid foundation for recommending assessment, coding, and marking techniques and methodologies. Key considerations include the following:

- Structural assessment procedures were fairly well-established for routine conditions, especially for bridges; however, for emergency situations, there were relatively few documented procedures available. Further, the few that were available are generally focused on bridges and earthquakes.
- These processes do not provide a uniform means for conducting these assessments or a common form of coding and marking. They typically do not consider traffic levels.
- Many agencies are currently preparing for emergency events and developing response plans; however, the focus has primarily been on bridges following an earthquake.

Table 2-10. Identified needs to improve structural assessment, coding, and marking procedures in emergency situations.

Q 32 – What needs have been identified by your agency to improve structural assessment, coding, and marking procedures in emergency situations?						
Rank	**Response**	**Average Rank**	**Max. Rank**	**Min. Rank**	**Median Rank**	**Standard Deviation**
1	Additional training	2.29	1	5	2	1.13
2	Increased number of inspectors	2.65	1	6	3	1.54
3	Access to more technologies	3.52	1	6	4	1.41
4	Published guidelines available to all agencies	3.85	1	6	4	1.69
5	Improved coordination between agencies	4.35	1	6	5	1.53
6	Additional resources such as vehicles and equipment	4.56	1	6	5	1.67
7	Other	6.81	1	7	7	0.91

- Similar levels of technology usage for inspections are anticipated during emergency response as currently used during routine inspections. However, smartphones and tablets were given higher priority for use in emergency events.
- Minimal literature is available describing coding and marking practices. Most available practices were included as a very small part of the assessment manual. For coding, many procedures use forms that are only sometimes compiled in a digital format. Marking processes are often based on a green (safe) to red (unsafe) system for the structure's status; although there is significant variability in how the marking is done as well as the number of colors used (typically three to five).
- Training is most frequently provided for scour, flooding, collision, and earthquakes. However, in general, minimal training is completed for other types of hazards. Periodic refresher courses and flip-books and pocket manuals were given the highest rankings with respect to desired training and other educational materials.

Overall, DOTs have several systems in place for routine inspections (e.g., using NBIS-based procedures); however, there were no comprehensive guidelines to address the wide ranges of emergency situations and their impacts on the various types of structures that DOTs are responsible for maintaining. The responses to the questionnaire also highlighted the importance of training materials and resources, including rapid methodologies for assessing, coding, and marking highway structures, to aid with the inspection process. Hence, the materials developed for this project fill a critical gap and provide valuable resources to transportation agencies.

CHAPTER 3

Evaluation of Assessment Technologies and Coding/Marking Practices

The objective of this chapter is to evaluate existing and emerging structural assessment practices and technologies for use in emergency situations and recommend methodologies appropriate for development of an assessment procedure and coding and marking guidelines. This chapter is divided into the following sections:

- Damage Characterization—This section summarizes the anticipated scale of damage to each structure type based on the hazard type and groups the various forms of damages reported in the literature into general types: structural, geotechnical, hydrological, and special case.
- Applicability Categorization—Each approach and practice identified in the literature review was categorized based on its suitability for use in assessing, coding, and marking highway structure damage in emergency situations. High-level categorization of technology application consists of human-centric, generic, and specific techniques. The maturity level of the technologies was also considered. Finally, the applicability rating was also presented in context of damage extent, scale, and type.
- Detailed Evaluation—Operational readiness as well as the technical data requirements of each technique was evaluated based on 13 categories: necessity for baseline data, frequency of updates, training requirements, measurement resolution, measurement accuracy, spatial coverage, operation, technology availability, processing and analysis time required, technological maturity, level of automation, security, and speed. A scoring system ranging from 1 to 5 was used to rank each technique's capabilities within each category. Explicit definitions are provided for each ranking to minimize subjectivity.

In general, there are a lot of technologies available to aid in the assessment, coding, and marking process. Because of the various levels of sophistication, each technology has its own place within the context of a damage assessment timeline [Fast Reconnaissance (FR), Preliminary Damage Assessment (PDA), Detailed Damage Assessment (DDA), and Extended Investigation (EI)] as well as within an SHA's current level of maturity or comfort with the technology. Hence, the focus on this chapter is to provide a solid understanding of each technology or process, and its potential applications, capabilities, and limitations, which will allow SHAs to select technologies that are appropriate for their organization.

3.1 Damage Characterization

In this section, two-dimensional matrices of the expected damage to highway structures by emergency event and type of damage are presented. The main objective of these matrices is to provide a basis for the transportation agencies to establish emergency response priorities and to facilitate selecting assessment methods that may need to be performed in case of different emergency situations.

First, the anticipated damage to highway structure types by emergency events is categorized in Table 3-1 as either significant, moderate, minor, or unlikely. This categorization is based on the

Table 3-1. Damage matrix in terms of emergency events and highway structures.

Structures	Emergency Event						
	Earthquakes	Tsunami	Tornado and High Winds	Hurricane and Storm Surge	Flooding	Scour	Fire
Bridges	Significant	Significant	Minor	Significant	Moderate	Significant	Moderate
Tunnels	Moderate	Minor	Unlikely	Moderate	Moderate	Minor	Significant
Walls	Moderate	Moderate	Unlikely	Moderate	Moderate	Moderate	Minor
Culverts	Moderate	Minor	Moderate	Moderate	Significant	Significant	Moderate
Embankments	Significant	Moderate	Moderate	Moderate	Significant	Significant	Unlikely
Overhead Signs	Moderate	Moderate	Significant	Moderate	Minor	Minor	Moderate

Damage Scale

(red)	Significant damage – Several collapses and irreparable damage to multiple structures across a large area.
(yellow)	Moderate damage – Repairable damage to several structures.
(green)	Minor damage – Localized damage to a few structures, most do not need significant repair.
(white)	Damage unlikely.

assumption that an emergency event has occurred that is significant enough to produce noticeable to significant consequences to at least one structure of interest. However, it is possible that a structure could experience a higher level of damage at extreme intensities of an emergency event or when subjected to prolonged exposure (i.e., the damage could jump one or two scale levels for specific combinations).

Next, Table 3-2 groups the various forms of structural damages into four general types: structural, geotechnical, hydraulic, and special case. These damage types were simplified from extensive literature review of the damage reports of previous emergency events.

Table 3-2. Common forms of damage per type.

Damage Type	Damage
Geotechnical	• Ground failure such as liquefaction, lateral spreading, landslides, etc. • Slope instability • Erosion • Bearing capacity failure • Active or passive failure • Foundation settlement
Structural	• Cracking and spalling of reinforced concrete members • Flexural and shear failures of reinforced concrete or steel members • Buckling, fracture, and tension failure of steel members • Fatigue damage, including low-cycle fatigue • Inelastic deformation and buckling
Hydraulic	• Scour • Debris impact • Inundation leading to hydrostatic and hydraulic pressures • Washout
Special Cases	• Thermal expansion • Reduction of strength and material properties due to thermal effects • Efflorescence causing deterioration • Decay of timber members • Corrosion

3.2 Applicability Categorization

3.2.1 Background

This section categorizes technologies, approaches, and practices identified in the literature review according to their technical applicability toward assessing, coding, and marking structures under emergency situations for potential damage identified in Table 3-1. The primary intent of this section is, from the perspective of technical applicability, to help agencies to select assessing techniques that match their backgrounds and current capabilities. Hence, the categorization is done from the user perspective, particularly to identify techniques that are most helpful for PDARs.

For a detailed review of various sensing technologies and their use, the interested reader is referred to Ahlborn et al. (2010) and Vaghefi et al. (2012), which classify and rate technologies based on their capabilities for specific bridge elements and measurements of interests. Most of these advanced technologies would be more appropriate for later assessment stages (e.g., DDA and EI).

The term "technique" used herein is a generalized notion, which includes all the assessing technologies identified in the literature review; more importantly, it includes no- or low-technology manual assessing, coding, and marking techniques. In this section, these methods will be mostly categorized as "human-centric" techniques.

For technological methods (that involve use of technological devices or equipment, or computing methods), the maturity of the technology and the maturity of the organization (or institution) that will be using the technology should be clarified. To proceed with the technology applicability evaluation, the research team considered the three MCEER maturity categories—operational, developmental, and research—and systematically selected the technologies that are mostly in the maturity category of *operational* (Tralli 2000).

3.2.2 Technique Applicability Category

The following categories of technique applicability are proposed:

1. *Human-centric techniques.* This category of techniques indicates that equipment or devices are not the dominant means in the practice; rather, a procedure is more emphasized that involves and is dominated by use of a human's scientific and empirical knowledge in the field. The applicability of human-centric techniques is general or simply "general use."
2. *Generic techniques.* This category is further divided into "generic simple" and "generic high-tech" techniques. The basic feature of this category is use of equipment or devices in the field, which generate data aiding or subject to a human's further analysis and decision making. The term "generic" implies that the applicability of generic techniques is general or "general use."
3. *Specific techniques.* Different specific situations will be defined in Subsection 3.2.2.3 for the techniques in this category. The applicability of specific techniques will be labeled as "specific use."

Each of these categories is described in more detail in the following subsections.

3.2.2.1 Human-centric Techniques

Human inspection using the trained "naked-eye" plays a significant role in routine practice and emergency response; even though, as reviewed earlier, human inspection-only techniques are significantly limited to identification of visually observed distresses and anomalies. It is recognized that almost all existing coding and marking practices are essentially a human-based in-situ operation. Therefore, human-based visual assessment, and existing coding and marking techniques, can be grouped and categorized as *human-centric techniques.*

3.2.2.2 Generic Techniques

There are many technological means, from simple to sophisticated ones, which can aid damage assessment. First, many of the assessment technologies in the literature review [e.g., digital cameras, smartphones/tablets, personal mobile computers, personal global position system (GPS) devices, and digital or paper-based GIS maps] are so simple to use and versatile that they can further facilitate human inspection in nearly all types of disaster events by identifying visible damage conditions. Second, a large number of sophisticated equipment/devices can be used in the field for performing advanced or accurate inspection in nearly all situations as well.

Use of these techniques typically requires high-technology data interpretation and training prior to their use. These techniques may include optical or radio satellite platforms; airborne optical imaging platforms [including unmanned aerial vehicles (UAVs) / unmanned aerial systems (UASs)]; airborne, terrestrial or water-borne geodetic sensing (e.g., lidar) equipment; and a few types of non-destructive sensing/imaging equipment. Therefore, the use of these technologies can be grouped into two subcategories: *generic simple techniques* and *generic high-tech techniques.*

1. *Generic simple techniques.* The simple techniques include many consumer-grade global navigation satellite system (GNSS) devices, portable computers, and mobile imaging devices (e.g., photo cameras or smartphones), which have become ubiquitous and can be used to aid human-centric inspection, assessment, and coding techniques. Simple devices require no minimal training or expertise to operate.
2. *Generic high-tech techniques.* Techniques that need either expert-level training for operation or advanced processing packages for data interpretation are considered high tech. Several high-tech imaging or point-cloud generation devices are in this subcategory. They include (1) satellite or airborne imaging, which can be used for all types of regional-scale disasters; (2) advanced geodetic devices such as laser scanning/lidar, which can be used along with different platforms, for example, fixed-wing, helicopter, vehicle, static and hand-held; and (3) thermal imaging, ground penetrating radar (GPR), sonar, and other simple non-destructive techniques. High-tech devices require significant training and experience to operate.

3.2.2.3 Specific Techniques

Many other equipment/device-based techniques are specific for applications in particular situations. Thus, from an applicability point of view, these technological techniques are categorized as *specific techniques.* These techniques may be used only for a certain type of emergency, structure damage type, or distress state or only when a certain condition is satisfied. Therefore, these techniques should be individually considered before use.

For example, bathymetric devices are well suited to underwater scouring detection during flooding events. Although applicable to general structures, structural sensing devices for real-time monitoring, such as strain gauges and optical fibers, are mostly applicable to the monitoring of stress and strain field in structures; more importantly, practical deployment of structural sensing devices is only for critical transportation structures. The use of crowdsourcing or other citizen-scientist techniques involve special call-to-action for public involvement, which is a specific condition to satisfy before using these technologies.

In addition to the foregoing categorized techniques, agencies should consider many non-device/equipment-based computing techniques (e.g., management software, databases/inventories, and emerging techniques such as crowdsourcing or smart apps). These databases, software, or computing applications are either necessary for a certain specific hardware device when used in specific situations or can facilitate the speed of analysis or communication. Therefore, they too are categorized as *specific techniques.*

3.2.2.4 Applicability Categorization Table

Table 3-3 is a high-level categorization of these assessing, coding, and marking techniques based on their individual applicability. Two notes are given regarding this table:

1. Common features of using any *high-tech* equipment are the generation of large data sets and the burden of data processing, which often require specialized software and training. It follows that one of the primary limitations that prevents most transportation agencies from using generic or specific high-tech assessment technologies is the preparedness and training that is required to support the complex data processing efforts. Therefore, many digital data processing and information management software packages are developed and treated as necessary accessories for using high-tech devices. Therefore in Table 3-3, it is assumed that, for all high-tech techniques (generic or specific), software packages for data processing and interpretation are associated with the high-tech device or equipment.
2. "Limited general use" is used to describe two non-destructive evaluation techniques—infrared and ground penetrating imaging methods—that can be used to inspect damage associated with multiple structural materials. The reason for categorizing them as "generic techniques" is that portable and easy-to-use devices for the two technologies are available and can be implemented quickly for a relatively wide range of applications; however, their use is restricted by their inability to be operated in all environments because of their hand-held or portable features.

3.2.3 General Technical Applicability Evaluation

Based on the applicability categorization scheme presented in Table 3-3, three additional high-level technical applicability evaluations are conducted in this subsection. The applicability evaluation is based on a straightforward decision-tree selection of assessing, coding, and marking techniques. The decision tree (Figure 3-1) starts with a basic identification of the extent of damage. If the damage extends to only a single structure, the level of damage and the type of damage are then determined. Subsequently the applicable technique is selected. The simple decision tree proposed in Figure 3-1 serves to evaluate technical applicability herein only. The actual technique selection process by transportation agencies relies on many other factors (which is further elaborated in Section 3.3). Based on this decision tree, the following subsections present the details of the high-level technical applicability evaluations.

3.2.3.1 Applicability in Terms of Damage Extent

When technical applicability of techniques is being evaluated, two basic levels of damage extent—multiple/distributed structures and single object—are considered as follows:

1. Multiple/Distributed Structures
   a. Definition: Disaster induces damage to transportation structures at a large geospatial scale that extends to multiple transportation structures or a distributed network of transportation structures (effectively the disaster extent may be at a community, city, state, and even a multi-state national scale).
   b. Applicable technique: Different remote sensing/GIS products are preferred (e.g., techniques 11, 12, 16, 19, and 20 in Table 3-3) and particularly crowdsourcing and modern mobile- and cloud-computing-based smart apps can be exploited (technique 34), if they are effectively deployed.
2. Single Structure
   a. Definition: All hazards may eventually damage individual structures, leading to local damage to different single structures. When selecting an assessing technique, two high-level identifications are necessary: the damage level and the damage type.
   b. Applicable techniques: Rely on the decision of the actual damage level and damage type.

Table 3-3. Technique categorization in terms of applicability.

Assessing, Coding, and Marking			Short Description and Uses	Applicability	Maturity
Category	#	Technique			
Human-centric	1	Human damage inspection	Naked-eye inspection of structural damage (e.g., collapse degree, crack/delamination types/degree and other surficial damage types).	General use	Operational
	2	In-situ coding	Manual coding using established protocols in the field. This is typically accomplished via a paper-based form completed by an inspector or a digital technology-based coding.	General use	Operational
	3	In-situ marking	Manual marking using established protocols in the field. This can include use of chalk, crayon, tapes of various colors, or digital codified patterns to communicate a structure's status or identify locations of damage warranting extended investigation.	General use	Operational
Generic Simple	4	Digital cameras	Digital imaging of damage or recording of events; retagging may be available for some cameras (including special portable cameras, e.g., camera on a stick).	General use	Operational
	5	Smartphones/tablets	For field communication, photo capturing, and processing simple tasks as personal computers.	General use	Operational
	6	Personal laptops/mobile computers	For personal field data logging, reporting, and simple computing, and other simple computing tasks.	General use	Operational
	7	Personal GPS/GNSS devices	For personal positioning, navigation, or tracing paths.	General use	Operational
	8	Cloth types/tape measures/Carpenter level/Calipers	For local marking, and obtaining distance/width/thickness or other measurements.	General use	Operational
	9	Compass/level	Mechanical or simple digital direction/level finding devices. Used to determine tilts and rotations on structures. It also can be helpful in determining impact direction in the case of hazards such as tsunamis.	General use	Operational
	10	Laser distance measures	For quick and short-distance measurements, especially for hard to reach locations.	General use	Operational
	11	GIS maps	Digital or paper-based maps for field guidance, such as general maps, terrain maps, and other special-purpose maps, e.g., FEMA flood maps, municipal parcel maps.	General use	Operational
	12	Satellite/airborne (optical or visually interpretable) images	Optical or other satellite/airborne images that have been processed hence enabling simple visual interpretation of damage extents.	General use	Operational
	13	Mobile (hand-held) three-dimensional imaging	Emerging technologies that capture "depth" in scenes besides 2D imagery intensities.	General use	Developmental
	14	Mobile imaging/video logging systems	Mobile (e.g., vehicle-mounted) imaging for recording surface damage or video-based surveillance of many types of events.	General use	Operational
	15	Inspection equipment	Simple inspection equipment (sounding hammer, chain drags, ice picks, dye penetrant, range pole or probe, plumb bob, etc.).	General use	Operational
Generic High-Tech	16	Mapping resource grade GPS	Advanced, mapping-grade GPS for large-scale positioning, locating, or tracing features.	General use	Operational
	17	Advanced laser range finder (Disto)	Advanced, laser range finding for large-scale applications, enable more advanced calculations such as area and volume to be calculated in field.	General use	Operational
	18	Simple airborne imaging (radio-controlled UAVs/UASs)	Simple imaging using unmanned technologies using low-cost miniature UAVs with radio control.	General use	Developmental
	19	Advanced airborne imaging tools (UAVs/UASs)	Advanced imaging using unmanned technologies involving geo-referenced imaging systems.	General use	Under research
	20	Lidar—all platforms (airborne, mobile, static terrestrial, underwater)	Advanced point-cloud mapping of structural damage for most damage types. Static terrestrial and underwater systems are applicable for component/site analyses, mobile for highway-level analyses, and airborne for large-extent applications.	General use	Operational
	21	Robotic total station	These systems can be used to measure deformations, deflections at discrete locations on structures.	General use	Operational
	22	Real-time kinematic GPS, permanently mounted GPS units	Trace features, measure centimeter-level deformations on a structure.	General use	Operational
	23	Thermal imaging (including analysis software)	Non-destructive infrared imaging of different types of surficial damage/distresses; expert-level visual interpretation is necessary.	Limited general use	Operational
	24	GPR (including analysis software)	Non-destructive radio imaging of different types of shallow-surface damage/distresses; expert-level visual interpretation is necessary.	Limited general use	Operational

Table 3-3. (Continued).

Assessing, Coding, and Marking			Short Description and Uses	Applicability	Maturity
Category	#	Technique			
Specific	25	Simple mechanical devices	Simple non-destructive or semi-destructive sampling devices for specific material strength evaluation (e.g., Schmidt hammer).	Specific use (field material types)	Operational
	26	Other non-destructive methods	Advanced non-destructive evaluation (NDE) methods for imaging and reconstruction of internal damage, such as x-ray, microwave imaging.	Specific use (internal damage)	Developmental
	27	Bathymetric vessel or robot-based survey	Advanced point-cloud underwater survey for scour or other hydraulic damage detection.	Specific use (underwater)	Operational
	28	Vehicle-mounted inspection system	Advanced NDE systems featuring real-time (considering real traffic speed) sensing and processing.	Specific use (traffic disturbance)	Under research
	29	Structural-monitoring sensors	Structural health monitoring technologies based on vibration signals and software-based data processing is usually needed. Typically capable of real-time information.	Specific use (technical and non-technical factors)	Operational
	29a	Accelerometers	Acceleration response for identifying structural modes or global damage condition.	Specific use (detailed global)	Operational
	29b	Strain gauges	Local strain gauges for identifying local deformation or damage.	Specific use (detailed local)	Operational
	29c	Fiber-optics-based sensors	Fiber-optics sensors or Bragg grating-based sensing that can be modulated for acceleration, strain, and temperature sensing.	Specific use (detailed global and local response)	Operational
	29d	Wireless sensor network	Wireless (without use of conventional cable for data acquisition) based on different wireless communication protocols.	Specific use (large-span critical structures)	Developmental
	30	Transportation structures inventory/databases (e.g., NBI)	State-level or national transportation data infrastructure; usually used for geospatially large-extent investigation or research purpose.	Specific use (when necessary and ready)	Operational
	31	Asset management software	Used for digital editing or adding of structural damage/condition information based on latest acquired data.	Specific use (when necessary and ready)	Operational
	32	Specific data analysis methods and software	Image processing, machine learning methods for semi- or automatic interpretation.	Specific use (when necessary and ready)	Operational
	33	Inspection management software (e.g., BIM)	Used for in-field inspection and data management.	Specific use (when necessary and ready)	Operational
	34	Emerging crowdsourcing, smart apps, and other citizen-scientist methods	Used for public-involved disaster damage reporting or informing the public; modern mobile and cloud computing and communication infrastructure supports are necessary.	Specific use (when public is called)	Under research

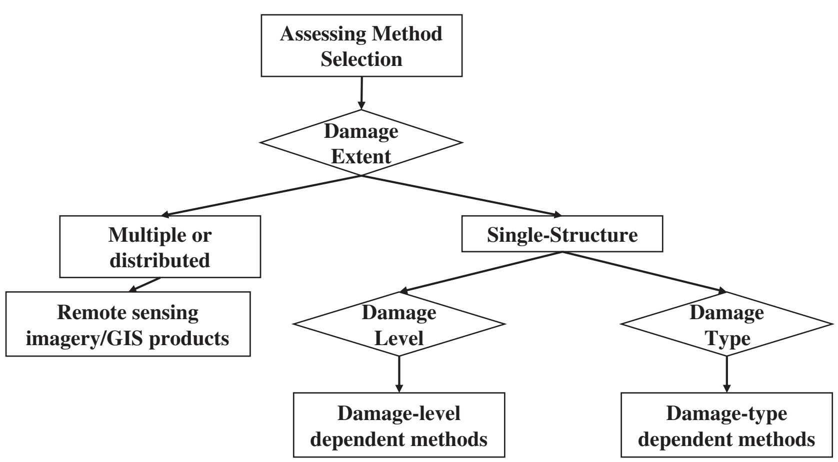


Figure 3-1. Assessing, coding, and marking technique selection based on technical applicability.

Table 3-4. Applicability of techniques in terms of damage levels.

Damage Level	Most Applicable Assessing, Coding, and Marking Techniques
Undetermined damage	Besides all possible generic techniques (4–24), all specific techniques (25–34) are needed for determining the type of damage.
Intact to minor damage	• If damage is **visible**, human-centric techniques (1–3) and generic simple techniques (4–15) can be used. • If damage is **hidden**, generic high-tech and specific techniques (16–34) can be used.
Moderate damage	Human-centric techniques (1–3) and generic simple techniques (4–15) are sufficient; some generic high-tech techniques (16–24) may be used as needed.
Major damage to collapse	Remote sensing (12) and human-centric techniques (1–3).

3.2.3.2 Applicability in Terms of Damage Level

For a structure extent, the level of damage determines the applicability of each assessing, coding, or marking method described in Table 3-3. The four damage levels are (1) undetermined damage, (2) intact to minor damage, (3) moderate damage, and (4) major damage to collapse of structure. The most applicable techniques for each of the four levels of damage are summarized in Table 3-4.

3.2.3.3 Applicability in Terms of Damage Type

When the type of the damage can be simultaneously determined by human-centric techniques while deciding the damage level, the applicability of assessing, coding, and marking techniques depends on the types of damage. Table 3-5 identifies the techniques that are applicable to each damage type. For a detailed analysis based on specific indicators of interest, consult Ahlborn et al. (2010) and Vaghefi et al. (2012).

3.3 Detailed Evaluation of Techniques

3.3.1 Introduction

This section will provide a detailed evaluation of each technique, both human inspection and assessment technology identified in Section 3.2. The intent of this evaluation is to aid in the decision-making process of when each technique would be suitable for use based on the emergency response timeline, magnitude of the event, availability of resources, skill set, and area impacted.

A total of 13 categories were used to evaluate the operational readiness as well as the technical data requirements of each technique in light of the emergency timeline. A numerical scoring system, designed with the intent of removing as much of the subjectivity from the process as possible, was used to establish a relative ranking of each technique.

3.3.2 Methodology

The approach begins by establishing the four critical stages of the emergency response timeline:

- Pre-event preparation
- Data collection/access
- Data interpretation
- Communication/reporting

Table 3-5. Applicability of techniques in terms of damage types.

Damage Type	Damage	Most Applicable Assessing, Coding, and Marking Techniques
Geotechnical	• Ground failure such as liquefaction, lateral spreading, landslides, etc. • Slope instability • Erosion • Bearing capacity failure • Active or passive failure • Foundation settlement	• All human-centric and generic simple techniques will be applicable because of the visibility of the damage in most cases. • For quantification, the generic high-tech technique, terrestrial lidar (20), is the most suitable for ground failure, slope instability, erosion, various capacity failure mechanisms, and foundation settlement.
Structural	• Cracking and spalling of reinforced concrete members • Flexural and shear failures of reinforced concrete or steel members • Buckling, fracture, and tension failure of steel members • Fatigue damage, including low-cycle fatigue • Inelastic deformation and buckling • Subsurface cracking/void/delamination damage of concrete; corrosion of steel rebars • Interior (invisible) damage	• When damage is visible, all human-centric and generic simple techniques (1–15) and simple to complex strength devices (25) for material strength characterization. • To enhance visibility, two generic high-tech techniques can be used: thermal imaging (23) for surface damage (e.g., cracking, spalling, flexure/shear/buckling/fatigue induced other damage patterns, etc.) and GPR imaging for other shallow subsurface damage; vehicle-mounted inspection system (28) for bridge deck. • For interior damage, advanced non-destructive evaluation techniques (26). • For all above structural damage, structural-monitoring solutions (29a–d) may be applicable for critical structures.
Hydraulic	• Scour • Debris impact • Inundation—leading to hydrostatic and hydraulic pressures • Washout	• All human-centric and generic simple techniques (1–15). • For volume (e.g., debris, inundation, and washout) characterization: terrestrial lidar (20). • For bridge foundation scour, either manual scuba diving or the bathymetric survey (27).
Special Cases	• Thermal expansion • Reduction of strength and material properties due to thermal effects • Efflorescence causing deterioration • Decay of timber members • Corrosion	• All human-centric and generic simple techniques (1–15). • For strength characterization, simple to complex strength devices (25) for material strength characterization. • Generic to specific NDE techniques (23, 24, 26).

Thirteen categories (Table 3-6) were then established to specifically evaluate the way in which each technique supports the sub-tasks of these four primary workflows. A scoring system ranging from 1 to 5 was used to rank each technique with the desired or most beneficial condition within a category receiving the highest score and the least beneficial receiving the lowest score under normally expected conditions. For example, when evaluating the requirement for training, a technique that involves a minimal level of training to complete a specific sub-task would receive a high score.

3.3.3 Assumptions

Given the potentially broad interpretation that could be applied to a number of the categories when scoring the techniques, the following assumptions were made to focus the evaluation on the primary scope of this project and to provide a more narrowly defined, objective context:

1. The intent is for the technique to be evaluated based on its use to rapidly assess, code, and/or mark highway structures during emergency situations.

Table 3-6. Categories and corresponding score.

Stage	Category	Score 1	Score 2	Score 3	Score 4	Score 5
Pre-event Preparation	Necessity for Baseline Data	Continual in-situ measurements	Multiple, periodic surveys required	Detailed data set/survey required	Basic data set required (e.g., drawings)	No data necessary
	Frequency of Updates	Real-time data, logged continually	Monthly	Annually	Every several years	Not required
	Training	Extensive (years of experience)	Significant (requires a course(s) months to years in length)	Moderate (up to speed with a few short courses)	Some (basic training in forms of short workshops and seminars)	Little to none
Data Collection/Access	Measurement Resolution	Several meters	Meters	Decimeters	Centimeters	Millimeters
	Measurement Accuracy	Several meters	Meters	Decimeters	Centimeters	Millimeters
	Spatial Coverage	Component/ element	Structure/ site	City/county	Statewide	Regional/ national
	Operation Duration	Very slow (weeks)	Slow (days)	Moderate (hours)	Fast (minutes)	Very fast (seconds)
	Technology Availability	Difficult to find/not available	Requires specialist to collect and obtain	Team can be mobilized or generally available consultant can be hired quickly to collect	Readily available for commercial fee	Readily available, free access
Data Interpretation	Processing and Analysis Time Required	Very slow (weeks)	Slow (days)	Moderate (hours)	Fast (minutes)	Very fast (seconds)
	Technological Maturity	Research	Pilot projects	Develop-mental	Becoming standard of practice	Operational
	Level of Automation	Full human interaction, manual data collection	Significant human interaction	Semi-automatic—mix of human interaction and automated tools	Automated, but results are available upon return to office	Automated, results are available in situ
Communication/Reporting	Security	Insecure	Basic security in place	Password protection	Password protection and encryption	Advanced security protocols combining hardware and software
	Speed	Paper-based or uncommon medium (weeks to days)	Hard-drive delivery (weeks)	Flash- or hard-drive delivery (days)	Internet	Internal data server

2. The primary scope of the investigation is based on an individual, single structure, unless otherwise indicated.

The technique is being evaluated under the normally expected use conditions. In special cases, a system may be capable of higher performance than what is described in this evaluation.

3.3.4 Definitions of Categories

Table 3-6 provides a brief description of how the scoring is defined for each category. The following definitions are intended to provide additional insight into the scoring process:

1. Necessity for baseline data – Refers to the level of baseline data needed in order to effectively apply the technique. The range is from continuous to none.
2. Frequency of updates – Refers to the need for baseline data updates in order to effectively apply the technique. The range can be from real-time continuous to none.
3. Training – Refers to the need for training in order to make effective use of the technique. The range is from years of experience to none.
4. Measurement resolution – Refers to the spatial, temporal, and/or spectral resolution or density of measurements or observations that can be normally obtained with the technique for the entire structure. The range is from several meters to millimeters or, when applicable, frequency range from low to high.
5. Measurement accuracy – Refers to the absolute measurement accuracy of the technique. The range is from meters to millimeters.
6. Spatial coverage – This category is an exception to the proposed scoring system in that the extent goes beyond an individual structure to include larger geographic regions. The range is from an individual structural component up to the entire United States.
7. Operation duration – Refers to the amount of time required to obtain the desired result from the use of the technique. The range is from weeks to seconds.
8. Technology availability – Refers to the relative availability of the technique, considering the availability of equipment, software, and experts. The range is from difficult to find to readily available.
9. Processing and analysis time required – Refers to the requirement for processing the data obtained by using a specific technique. The range is from weeks to seconds (real time).
10. Technological maturity – Refers to the stage of maturity of the technique. The range is from the technique being in the research stage to fully operational (discussion of this is found in Section 3.2).
11. Level of automation – Refers to how automated the process is for obtaining a result. The range is from completely manual to fully automated.
12. Communication security – Refers to the level of security associated with the transmission of data via manual recording, digital storage, or digital communication network (e.g., Internet, 3G/4G network). The range is from no security to the highest level.
13. Communication speed – Refers to the speed of digital data transfer. The range is from days/weeks to the speed delivered by a high-speed digital network.

3.3.5 Evaluation

Table 3-7 provides the scoring for each technique as evaluated within each category. These scores are an important relative indicator of the potential value of each technique in the assessing, coding, and marking of structures in emergency situations.

Table 3-7. Evaluation of assessing, coding, and marking techniques for use in emergency situations.

Assessing, Coding, and Marking Techniques		Pre-event Preparation			Data Collection/Access					Data Interpretation			Communication/ Reporting	
		Necessity for Baseline Data	Frequency of Updates	Training	Measurement Resolution	Measurement Accuracy	Spatial Coverage	Opera-tion Duration	Technology Availability	Processing and Analysis Time Required	Technological Maturity	Level of Automation	Security	Speed
Human-centric	Human damage inspection	5	5	1 to 4	4	5	2	3	2 to 3	4	5	5	2	n/a
	In-situ coding	5	n/a	1 to 4	n/a	n/a	2	5	3	5	5	5	4	n/a
	In-situ marking	5	n/a	3 to 4	n/a	n/a	2	5	3	5	5	5	4	n/a
Generic Simple	Digital cameras	5	5	5	2	3	2	5	5	5	5	5	4	5
	Smartphones /smart tablets	4	5	5	2	2	2	5	5	5	4	5	4	5
	Personal laptops/mobile computers	3	5	4	2	2	2	5	5	5	5	5	3	5
	Personal GNSS devices	5	5	4	2	2	3	5	5	4	5	5	4	4
	Cloth types/tape measures/ carpenter level/calipers	5	5	5	1	4 to 5	1	4	5	4	5	5	5	5
	Compass/level	5	5	4	1	4	1 to 2	4	4	4	5	5	5	5
	Laser distance measurement devices	5	5	3	1	5	2	4	4	4	5	5	5	5
	GIS maps	3	3 to 4	3	1 to 2	2 to 3	5	5	4	4	5	5	5	4
	Satellite/airborne (optical or visually interpretable) images	3	3 to 4	3	3	1	5	2	3	2	5	5	5	4
	Mobile (hand-held) three-dimensional imaging	5	5	3	4	4	2	4	3	3	3	4	5	3
	Mobile imaging/video logging systems	5	5	4	3	2	5	3	3	2	5	3	5	3
	Inspection equipment	5	5	5	3	3	1	4	5	4	5	4 to 5	1	1
Generic High-Tech	Mapping resource grade GNSS	5	5	3	2	3	2	4	4	4	5	3	5	4
	Advanced laser range finder (Disto)	5	5	3	1	5	2	5	4	5	5	5	5	5
	Simple airborne imaging (radio-controlled UAVs/UASs)	5	5	2	4	3	2	4	2	3	2	3	4	4
	Advanced airborne imaging tools (UAVs/UASs)	5	5	1	5	4	3	4	2	3	2	3	4	4

Generic High-Tech	Lidar—all platforms (airborne, mobile, static terrestrial, underwater)	5	5	1	5	4 to 5	2 to 5	3 to 4	3	3	4	3	5	3
	Robotic total station	5	5	2	1	5	2	3	4	4	5	5	5	5
	Real-time kinematic GPS, permanently mounted GPS units	1	1	2	1	4 to 5	2	3 to 5	4	2	5	3	4	4
	Thermal imaging (including analysis software)	5	5	1	3	3	1 to 2	3	2	2	5	3	5	3
	GPR (including analysis software)	5	5	1	3	3	2	3	2	2	5	3	5	3
Specific	Simple mechanical devices	5	5	5	1	4	1	5	4	4	5	5	5	5
	Other non-destructive methods	5	5	3	1	4	1	5	3	4	5	5	5	5
	Bathymetric vessel or robot-based survey	5	5	1	3	2 to 3	2	3	3	2	5	3	5	3
	Vehicle-mounted inspection system	5	5	2	3	4	3	3	3	2	4	3	5	3
	Structural-monitoring sensors													
	a. Accelerometers	1	1	2	1	5	2	3	3	3	5	3	5	4
	b. Strain gauges	1	1	2	1	5	2	3	3	3	5	3	5	4
	c. Fiber-optics-based sensors	1	1	2	1	5	2	3	3	3	5	3	5	4
	d. Wireless sensor network	1	1	2	1	5	2	3	3	5	3	3	3	5
	Transportation structures inventory/databases (e.g., NBI)	2	3	2	1	4	4 to 5	4	3	4	5	5	4	4
	Asset management software	3	3	3	1	2	5	4	4	4	4	5	4	4
	Specific data analysis methods and software	2	2	3	1	2	5	4	3	2	4	4	4	4
	Inspection management software	2	3	3	1	2	2	4	3	4	5	5	4	4
	Emerging crowdsourcing, smart apps, and other citizen-scientist methods	4	3	4	1	1	5	4	5	4	4	5	1	4

n/a = not applicable

CHAPTER 4

Assessment Process

This chapter provides a high-level overview of *Volume 2: Assessment Process Manual*. In addition, this chapter identifies the rationale used in the development of *Volume 2: Assessment Process Manual* and the key points in the assessment process developed for this project. Assessing is defined as the process of evaluating a structure's condition through inspection and possible data analysis or modeling. This process can be completed manually or through technological means.

4.1 Introduction

The purpose of this project was to provide a rapid, effective process for the assessing, coding, and marking of highway structures in emergency situations that can be implemented by SHAs across the United States. Although this process was developed with the intent of being adopted nationwide, the document focuses on procedures that can be implemented at the state and/or local transportation agency level. The assessment process was developed to fit easily within the context of the overall emergency response life cycle (see Table 4-1) and includes pre-event planning, training, appropriate technology usage, prioritization strategies, coding and marking, coordination, communication, inspection procedures, and redundancy. The intent of *Volume 2: Assessment Process Manual* is to define a clear process and to provide the tools necessary to effectively and uniformly assess, code, and mark highway structures in emergency situations.

The primary audience for *Volume 2: Assessment Process Manual* includes the senior managers, engineers, and inspectors who will have the responsibility to coordinate emergency response and determine if structures are safe for the traveling public during and after emergency events. These could include, but are not limited to, managing engineers, chief structural engineers, chief geotechnical engineers, chief hydrological engineers, chief mechanical engineers, chief materials engineers, and their supporting staffs. Additionally, *Volume 2: Assessment Process Manual* is of use within the planning and preparation phases, which could be led by SHAs' emergency response coordinators and heads of maintenance and safety.

4.2 Rationale

The assessment process developed for this project was based on a review of the published literature, DOT responses to the questionnaire, and technique evaluations. The assessment process was largely based on approaches currently used by several state agencies and DOTs including NYSDOT (O'Connor 2010), WSDOT (Reed and Wang 1993), MSP (2013), Utah DOT (2014), and Caltrans.

Table 4-1. Key phases in emergency response and events life cycle.

Phase	Timeline	Components
Planning and Preparation	(–) Now to Day 0	• Identify vulnerable structures and categorize • Prioritize and perform maintenance and upgrades on structures, following a prioritized list, if available and based on availability of funds • Acquire baseline data and analyze potential impacts to key structures • Instrument structures, if possible • Develop response plans and procedures for a number of scenarios • Perform what-if analyses and update plans and procedures as needed • Assign inspection ownership for each structure and highway segment, if possible • Identify safe zones and centralized reporting locations • Research and review best practices and lessons learned • Perform training and drills • Coordinate with other agencies • Publish communication protocols and procedures • Perform regional analysis to develop priority inspection list • Assemble list of potential first responders and PDARs for emergency task force • Develop guidelines for repairing damaged structures
Advance Notification for some emergencies (e.g., hurricanes) but not with others (e.g., earthquakes)	(–) Few days/ hours prior to Day 0	• Review emergency procedures • Review communication procedures • Implement evacuation plans • Alert response teams • Close traffic near most-vulnerable structures • Identify special needs and begin coordination with other agencies • Collect and update emergency task force • Report for duty (physically or through conference call) • Perform initial regional analysis to develop/update priority inspection list
Emergency Event / Initial Response*	Day 0	• Complete tasks listed in Advance Notification if not already done • Perform FR, when deemed necessary • Initialize PDA starting with critical and essential structures, including coding and marking of structures, as needed • Close impacted routes and set up detours in coordination with other agencies • Communicate with public as appropriate
Site Inspections	Days to weeks	• Continue PDA—assess, code, and mark, as needed • Build temporary structures/bracing • Optimize DDA through regional assessment and coordination • Perform load rating / load analysis when required • Coordinate with other agencies and close/open routes
Regional Assessment	Weeks	• Document areas of impact and damage • Document which highway structures experienced damage • Perform EI on required structures • Develop damage cost estimates to support requests for federal relief funds • Build temporary structures/bracing
Initial Recovery	Weeks to months	• Prioritize and begin repairs • Document procedures • Open routes • Build temporary structures
Economic Recovery	Months to years	• Repair or re-build structures
Continued Recovery	Years	• Review lessons learned • Prioritize upgrades • Continued maintenance • Update strategic plans and emergency response procedures • Go back to Planning and Preparation phase

**Additional events may occur such as earthquake aftershocks or a tsunami following an earthquake that need to be accounted for as well.*

The assessment process was developed based in large part on its ability to satisfy the following attributes:

- **Practical**—The methodologies must be practical; that is, they must be realistically implementable in diverse organizational structures of a variety of transportation and emergency agencies.
- **Cost-Effective—**The methodologies must fit within the budgetary constraints of the SHAs. Thus upfront, maintenance, and training costs are considered. In addition, methodologies are considered based on their ability to rapidly assess damages that can be tallied and submitted to FEMA for emergency relief funds.
- **Ease of Use**—The recommended methods need to be simple to use with sufficient documentation so that they can be learned "on-the-fly" by untrained first responders, if necessary. Easy-to-use methodologies require minimal pre-event training and keep annual training costs to a minimum. In addition, simple methods reduce implementation errors that may occur during emergency events.
- **Multi-tiered**—The methodologies and procedures considered must be capable of supporting inspectors with varying levels of skill and expertise. For instance, if the first responders are not confident in their ability to make a decision, the methodology should support a process for escalating a request for a more detailed review by a higher skilled person.
- **Redundant**—The proposed methodologies need to have overlapping capabilities with multiple communication avenues and backup plans to build redundancy into the rapid assessment process. This will encourage efficient communication between all parties and will ensure that all highway structures are safely opened for use as soon as possible.
- **Flexible**—The recommended methods need to be flexible in order to ensure suitability for multiple types of emergency situations (e.g., earthquake, tsunami, tornado, hurricane, storm surge, high winds, flooding, scour, fire, and other similar events); multiple types of highway structures (e.g., bridges, tunnels, culverts, walls, embankments, and overhead signs); multiple ranges of traffic levels; and the varying organizational structures of the multiple agencies involved (e.g., local, state, and/or federal).
- **Assessment Rate—**Time is critical in emergency response. Thus, the speed at which structures can be assessed is an important evaluation criteria.
- **Fail-Safe**—Each assessment technique needs to be analyzed in terms of the consequences of failure of that assessment technique and assessment system. Redundancy can overcome some of these limitations, but each technique needs to first be judged on its own merits.

4.3 Planning and Preparation

The goal of the planning and preparation phase is to anticipate as many of the likely emergency scenarios as possible so that the needed response can be identified, planned, and effectively coordinated with a minimum of crisis management. Proper planning can ensure that limited resources for data collection (including installation, training, and maintenance of equipment for inspection) are available and optimally allocated. During this vital planning phase, regional factors, interagency needs, and communication issues will be identified and addressed in a non-emergency environment. Access by inspectors to all available information (which can vary significantly) can be planned and tested under simulated event conditions (e.g., ShakeOut earthquake drills).

While specific guidance for all work necessary at the planning and preparation stage is not directly within the scope of this project, it is important to discuss relevant preparatory tasks and efforts that can provide the foundation for the emergency response procedure presented

in *Volume 2: Assessment Process Manual*. The relevant tasks and efforts are described in detail in *Volume 2: Assessment Process Manual* and outlined in the following list of key recommendations:

- Developing Emergency Operations Plans
  - Incorporate structural assessments and procedures into the current EOP
  - Establish the coordination process within the broader missions of the agency
- Data Infrastructure and Asset Management
  - Place quick-response (QR) codes on structures during routine inspections
  - Identify what data and software are needed to coordinate an emergency response
  - Identify the current status and quality of data infrastructure—improve if needed
  - Establish a timeline for updating data infrastructure
  - Provide recommendations on improving data collection during bridge inspection and asset management inventories
- Equipment and Resource Infrastructure
  - Establish a list of resources needed for emergency response
  - Identify which resources typically used for regular operations are needed for emergency response
  - Determine appropriate technologies and workflows that can be used for emergency response
  - Establish an appropriate percentage of agency funding resources to be put toward emergency response preparation
  - Identify what upgrades are needed for mobile phone, tablet, and database software and establish plans for when and how often they should be updated
- Emergency Event Planning
  - Establish a list of possible emergency events
  - Correlate which areas and highway structures are likely to be affected during specific emergency events
  - Identify critical highway routes and establish lifeline routes (Lifeline routes can be dependent on different businesses that are needed for economic recovery and well-being.)
- Traffic Levels and Capacity
  - Identify highways based on their attributes and functional classification
  - Identify traffic levels such as average daily traffic and average annual daily traffic
- What-If Analyses
  - Establish ShakeMap and ShakeCast scenarios for bridges during earthquakes
  - When applicable, establish scenarios for other emergency events
  - Update relevant structure data to provide more accurate scenarios
- Preparation for PDARs
  - Familiarize PDARs with their routes
  - Identify alternate PDAR routes
  - Establish a list of personnel that can be used for emergency response
- Training
  - Identify procedures needed to obtain additional staff
  - Prepare appropriate training materials
  - Determine an appropriate amount of time that should be dedicated to training materials
  - Provide a list of personnel needed during training
- Communication, Coordination, and Preparation
  - Establish intra- and interagency communication protocols and strategies
  - Update contact information regularly

4.4 Assessment Stages

The assessment of highway structures during an emergency situation will be accomplished using a four-stage process: Fast Reconnaissance, Preliminary Damage Assessment, Detailed Damage Assessment, and Extended Investigation. The primary scope of this project was to address rapid assessment (i.e., the FR and PDA stages). The DDA and EI stages will generally be completed using standard structural inspection operating procedures that reflect the specific needs and approach of each SHA. Hence, the DDA and EI stages will be briefly introduced in *Volume 2: Assessment Process Manual*, but detailed methodologies for the different highway structures and hazards were not developed in this project.

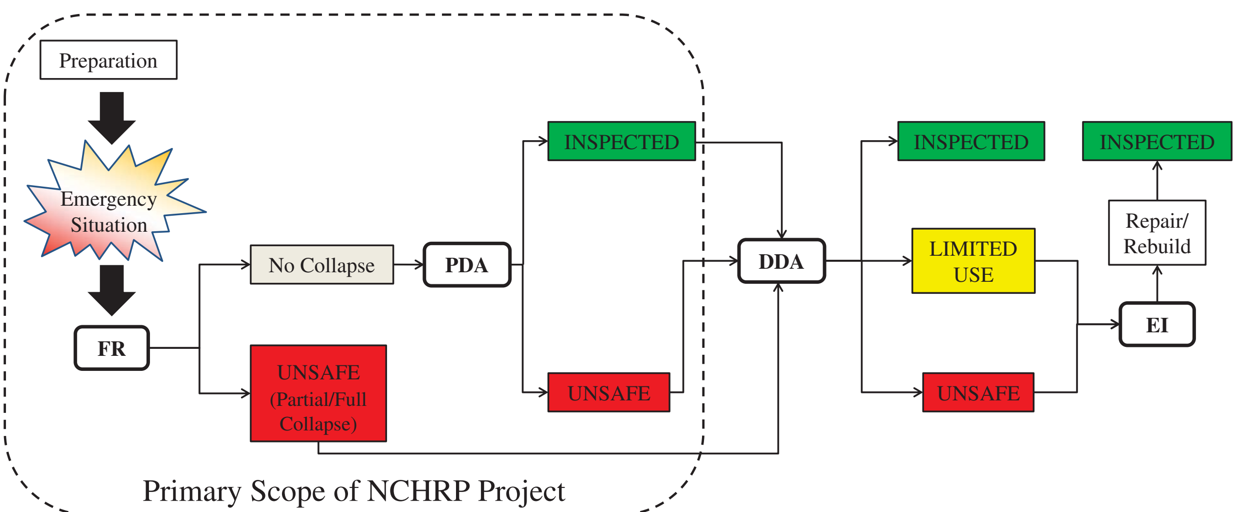
The four stages are based on methods currently in use throughout the United States (ATC 1995, 1; O'Connor 2010; Reed and Wang 1993). This multi-tiered approach is aimed at making the best use of the limited resources with the appropriate skill and expertise, while maximizing assessment rates and providing redundancy to the process in order to maximize safety.

Figure 4-1 presents an overview of the assessment process for a single structure and the interaction of the assessment stages along with the possible coding and marking classifications for a structure. The coding and marking classifications are described further in Chapter 5. Table 4-2 summarizes the objective and primary deliverables of each assessment stage.

4.4.1 Fast Reconnaissance

The objective of the FR assessment stage is to provide a global perspective and to establish/update the extents of the damage region as necessary. While FR should be completed at all response levels (discussed in Section 4.5), the type and detail of FR will depend heavily on the size of the event. A basic FR should be completed within 4 to 6 hours of the event. The five possible FR methods are as follows:

1. Pre-event or real-time disaster hazard mapping products
2. Rapid remote sensing
3. Crowdsourcing



UNSAFE = The structure requires further evaluation in the next assessment stage prior to being open to traffic.
LIMITED USE = Potentially dangerous conditions are believed to be present and usage is restricted to ensure public safety.
INSPECTED = The structure appears to be in the same condition as it was prior to the event.

Figure 4-1. Outline of assessment stages and subsequent primary level of coding.

Table 4-2. Damage assessment stages.

	Fast Reconnaissance (FR)	Preliminary Damage Assessment (PDA)	Detailed Damage Assessment (DDA)	Extended Investigation (EI)
Objective	Global perspective	Rapid route reconnaissance	Detailed inspection	Special study to address a particular concern
Scope	All structures in affected area	All structures in affected area, starting with priority routes	Structure and site specific	Site specific, as needed
Inspection Method	Helicopter, small fixed-wing aircraft, UAVs, and other “fast” methods	Drive-through with quick stop at each structure	Inspection and special access equipment as needed, load rating and remaining strength analysis	Any special equipment that is needed
Personnel	Chief engineers or managing engineer in aircraft or vehicle; specialized technicians as needed; the public	PDARs—Trained emergency responders (maintenance & operations crews, design engineers)	Routine inspectors and specialists (e.g., structural, geotechnical, hydrological, mechanical, materials)	Specialists (e.g., structural, geotechnical, hydrological, mechanical, materials)
Time Frame	Immediate (within 4–6 hours)	Immediate (within 24 hours)	Start ASAP (usually within 8 hours) and continue as necessary	Subsequent to DDA
Outcome	Determine the geographic extent of damage Identify impassible routes and traffic bottlenecks Locate structures that have major damage or are obviously unsafe Suggest priority for ground assessments	Determine the extent and type of damage Identify/confirm impassible routes and traffic bottlenecks Close unsafe structures Code and mark Recommend DDA for damaged or suspect structures Preliminary damage level estimate	Code and mark as necessary Close unsafe structures Recommendations for restriction, repair, or further investigation Preliminary cost estimates for agencies such as FEMA Reopen structures deemed safe that were closed as a precautionary measure during PDA survey Damage level estimate	Code and mark as necessary Detailed damage analysis Provide specific recommendations on necessary restrictions and/or repair Approximate cost estimate for remedial work
Deliverable	Reconnaissance report with maps, geo-referenced photos, and/or video that defines the affected region	Digital PDA form/ database (one entry per structure) and physical marking on the structure	DDA report for each structure and daily summary report	Special engineering report
Coding Options	UNSAFE	UNSAFE, INSPECTED	UNSAFE, LIMITED USE, INSPECTED	UNSAFE, LIMITED USE, INSPECTED

Source: Modified from O’Connor (2010).

4. Small or micro UAV-based imaging
5. Detailed FR techniques such as aerial reconnaissance (e.g., helicopter or small fixed-wing aircraft)

Any of these FR methods are useful to quickly assess multiple structures within a region and to help inform the prioritization of ground PDAs and DDAs. This information should also quickly be fed to traffic agencies and engineers who can identify and create appropriate detour routes, minimizing traffic congestion problems that can lead to accidents or slow recovery efforts.

4.4.2 Preliminary Damage Assessment

The PDA stage is performed immediately following an incident, likely within hours, to provide information on the need for action such as road or bridge closures and to define immediate

remedial action if needed (see Figure 4-1). It is expected that this may take a few minutes to 30 minutes per structure depending on the type of structure, degree of damage, and accessibility constraints. The ground/on-site PDA will be conducted by PDARs who will use digital cameras or other mobile devices to take pictures, preferably geo-tagged, and make brief written reports of their observations on each structure. SHAs are strongly encouraged to develop apps for mobile devices that can be filled out on the field (discussed in Chapter 6). PDA photos and reports will be uploaded into an emergency inspection management system or agency equivalent. If connectivity is available during the emergency incident, uploading will occur remotely at the site, if not, this will occur upon return to central command. This type of assessment includes a preliminary percent damage estimate of the structure, which is used for prioritizing DDA. These estimates could be also used to develop preliminary damage cost estimates for the incident that can be refined with DDA and EI.

4.4.3 Detailed Damage Assessment

The DDA stage is performed as soon as possible following an UNSAFE rating from a PDA, likely within 8 hours of the incident, if needed, and will continue as necessary to provide an evaluation of the structural damage levels and decisions on use restriction, or the need for an EI (see Figure 4-1). This is a "damage inspection" as defined by the MBE. It is not considered a rapid assessment for an emergency situation and is therefore beyond the scope of this project. The DDA is described in *Volume 2: Assessment Process Manual* for completeness and to ensure the overall process is clearly defined as well as to ensure a smooth transition between the inspection stages.

4.4.4 Extended Investigation

The EI stage is performed as soon as possible following an UNSAFE or LIMITED USE rating from a DDA. This is an "in-depth inspection" as defined by the MBE and may also include a "special inspection" or an "underwater inspection." It would also likely entail specialized technologies. Reporting of the findings from an EI follows the NBIS and other standard SHA operations. The EI is not considered a rapid assessment for an emergency situation and is therefore beyond the scope of this project; however, this stage should be considered during planning and the DDA stage such that the process can transition from rapid emergency assessment into recovery and day-to-day operations.

4.5 Response Levels

Responses levels relate to the immediacy of the response, the level of resources, and the effort that will be put into a response during an emergency event. They are essentially a status alert that can help ensure everyone is on the same page as to the magnitude of the response effort. As an example, a large earthquake (e.g., M_w7.0) creating damage over a dispersed geographic region will require a different method of response for structural assessment compared to a smaller event (e.g., M_w4.0 earthquake) where damages will be more localized and of lesser intensity.

Use of response levels can help a SHA prioritize resource allocation, strategize their emergency response, determine which assessment stages are necessary, know when outside resources will be needed, and refine selection of inspection routes. Identifying these levels prior to the event will help improve coordination and communication of the response.

Volume 2: Assessment Process Manual presents four response levels. Each SHA has to determine the appropriate criteria for each level of response. During an emergency event, SHAs can decide to escalate or reduce a response level as more information becomes available. As an example, a SHA may choose the following strategy to help in their response:

Level I Regular inspectors in the affected region(s) are placed on call to perform PDA. Teams are mobilized when the managing engineer determines that some damage has occurred based on FR observations.

Level II SHAs complete PDAs with their maintenance crews and DDAs using inspection crews. Additional personnel such as design engineers are placed on call and mobilized to assist with PDAs when the managing engineer deems appropriate.

Level III Inspectors focus directly on DDAs, while maintenance crews, design engineers, and others (as needed) in the region are immediately mobilized to perform PDAs. Inspectors from other regions could be placed on call to assist. External consultants from local firms who are appropriately trained could be utilized, as necessary. Federal assistance and coordination may also be required.

Level IV In addition to the mobilization strategy in Level III, the SHA requests immediate assistance from inspectors, maintenance crews, design engineers, and external consultants from other districts/regions to assist with the PDAs. Significant federal assistance and coordination may be necessary.

Figure 4-2 provides a process flowchart for the emergency response following an emergency event. FR should be conducted for all response levels; however; it should be refined according to the severity and geographic extent of the emergency event. Upon receiving an emergency notification, emergency management officials should first validate the warning. Once the warning has been confirmed, structure priority routes should be reviewed and planned for inspection. Response levels corresponding to different emergency events are detailed in subsequent sections. For purposes of this manual, emergency events with similar characteristics were grouped together for simplicity when defining response levels. Therefore, response levels were defined for the following emergency events:

- Earthquake
- Tsunami
- Tornado and high wind
- Hurricane wind
- Storm surge
- Flooding
- Fire

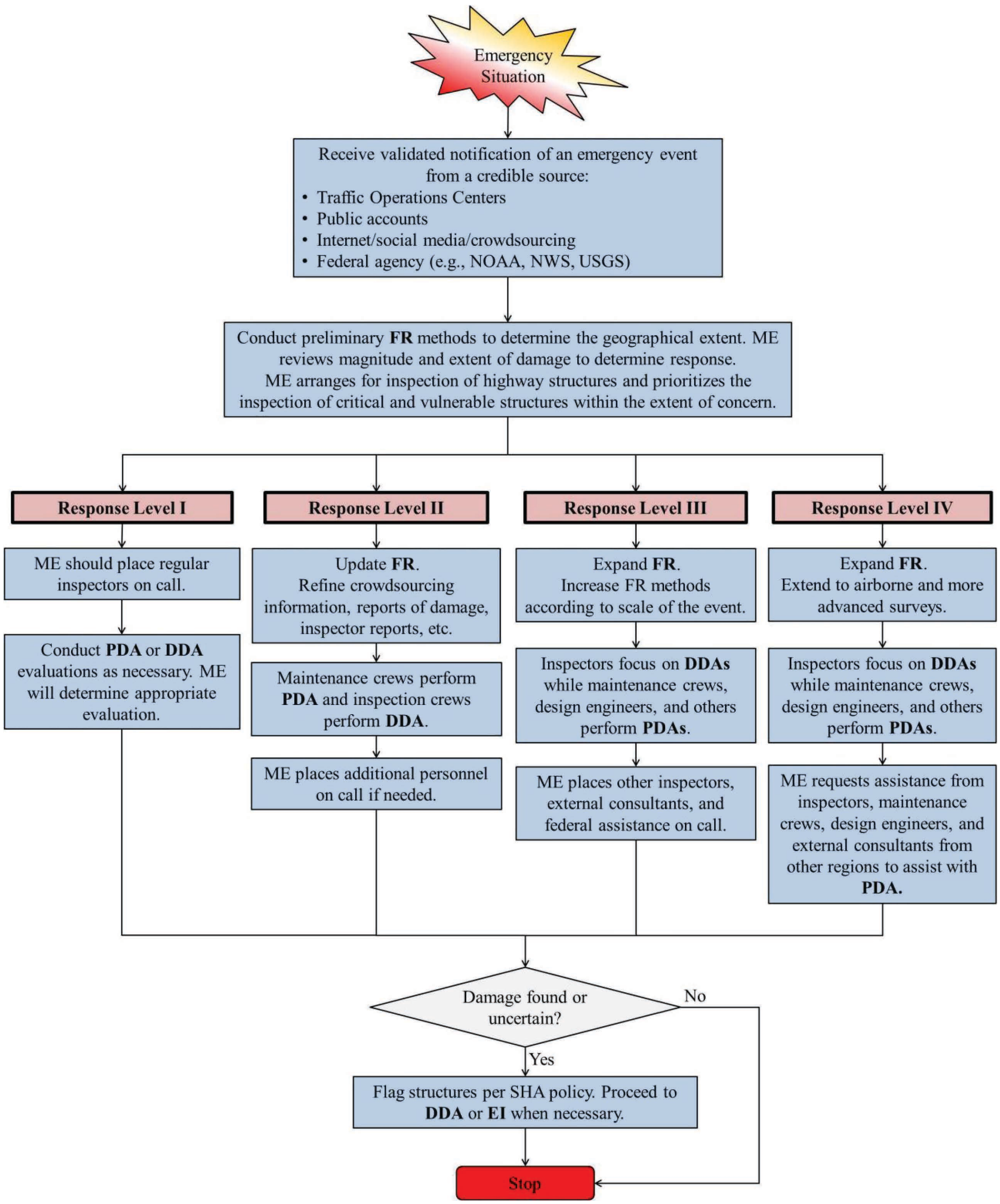
4.6 Supporting Technology

Assessment tools and technologies (both simply referred to as “technologies” herein) range from simple devices and field tools to high-tech sensing and computing equipment. Technologies are indispensable in responding to emergency events and in assessing damage to highway structures both during emergency situations and day-to-day operations. In addition, technologies can play a vital role in efficient and effective coding and marking.

This section recommends assessing, coding, and marking technologies that are appropriate to identify, evaluate, map, or quantify damage on highway structures. Technological recommendations can be suggested for all four assessment stages (FR, PDA, DDA, and EI) described previously; however, due to the scope of the project, technologies for the FR and PDA stages are considered in detail.

4.6.1 Technologies for Fast Reconnaissance

Efficient and effective FR quickly provides an overview of the geographic extents of the damaged region as well the overall severity of the damage. It is based on rapid technology-based observation and/or reporting from both the SHA personnel and the public. For example, the



ME = Managing Engineer

Figure 4-2. Response level process flowchart.

Table 4-3. Predictive hazard forecasting, loss estimation, and near-real-time hazard mapping technologies prior to and supporting FR operations.

Pre-emergency Event Assessment Technology	General Availability Classification	Available Resources
Hurricane forecast and simulation	Available for use	NOAA National Hurricane Center (www.nhc.noaa.gov) and Hurricane Forecast Improvement Program (www.hfip.org)
Tornado and storm forecast	Available for use	NOAA Storm Prediction Center (www.spc.noaa.gov/products/wwa)
Hazard modeling-based loss estimation for earthquakes, flooding, and hurricanes	Available for use	FEMA Hazus loss estimation (www.fema.gov/hazus) and USGS ShakeCast (earthquake.usgs.gov/research/software/shakecast)
Transportation inventory/ databases	Available for use	National Bridge Inventory database (www.fhwa.dot.gov/bridge/nbi.cfm)
Seismic shaking maps	Available for use	USGS ShakeMaps (earthquake.usgs.gov/earthquakes/shakemap)
Seismic deformation and aftershocks forecast	Emerging	E-Decider project (www.e-decider.org)

FEMA = Federal Emergency Management Agency, NOAA = National Oceanic and Atmospheric Administration, USGS = United States Geological Survey

GIS map products resulting from an FR that display the extents and communicate the severity of damage across those extents will provide key guidance in prioritizing routes for engineers conducting manual inspections (e.g., PDA).

Various predictive, near-real-time hazard, or disaster mapping products can be utilized immediately after (or prior to in some cases) the event to understand the extent and intensity of the emergency and even provide estimates of the likely damage from the event. Examples are included in Table 4-3.

Various FR technologies (Table 4-4) for data gathering are recommended for quickly assessing spatially distributed highway structures and networks within a region as well as to inform the prioritization of on-the-ground assessments. The most commonly used technologies include (1) citizen-based or public reporting through SHA operation centers or the national 511 travel information system and (2) helicopter or small-aircraft-based overview survey.

4.6.2 Technologies for Preliminary Damage Assessment

The PDA stage is performed immediately following an incident, likely within hours, to provide information on the need for action such as road or bridge closures and to define immediate remedial action if needed. GIS-based preliminary damage mapping from the FR stage will provide two key decision-making elements for the PDA activities. First, a critical list of highway structures that demand further evaluation will be noted in a digital or paper-based mapping product for PDA. Second, an optimal route that facilitates the inspectors' access to the structures can be generated.

Table 4-5 summarizes technologies suitable for PDA as well as their general availability, classifications, and resources. These technologies emphasize rapid inspection and data recording when working with highway structures or their structural elements.

4.7 Coordination and Communication

This section will describe two of the fundamental elements of an emergency response plan: coordination and communication. Although it is difficult to separate the two, coordination will be treated as primarily involving human resources, while communications will focus on the network itself.

Table 4-4. Post-emergency event observation-based FR technologies.

Post-emergency Event Technology	General Availability Classification	Available Resources
Public reporting (i.e., through phone calls) to the SHA's transportation operation/ management center	Commonly used	Examples include Virginia DOT's Report a Problem (www.virginiadot.org/travel /citizen.asp) and Delaware DOT's Report a Road Condition (www.deldot.gov /ReportRoadCondition/)
Helicopter or small-aircraft-based aerial survey	Commonly used	NA
Commercial satellite/airborne sensing (providing optical or visually interpretable images)	Available for use	USGS Hazard Data Distribution System (hddsexplorer.usgs.gov) or the International Charter (www.disasterscharter.org)
Community-based oblique imaging	Available for use	FEMA Civil Air Patrol program (www.capvolunteernow.com)
Advanced GIS integration and interoperability technologies	Emerging	Esri web-based disaster response GIS service (www.esri.com/services/disaster-response) XchangeCore framework for interagency information reporting, sharing, and interoperability (www.xchangecore.org)
Low-cost airborne imaging (e.g., radio-controlled or GPS way-point UAVs or UASs) at a regional scale	Emerging	Research at University of Vermont funded by U.S. DOT (www.uvm.edu/trc/transportation-research-center-uas-project-awarded-new-round-of-grant-money)
Crowdsourcing through professional or the general public communities using smart apps	Emerging	SpotOnResponse (www.spotonresponse.com) and FEMA Rapid Observation of Vulnerability and Estimation of Risk program (www.fema.gov/earthquake-training/rapid-observation-vulnerability-and-estimation-risk)

FEMA = Federal Emergency Management Agency, USGS = United States Geological Survey

Table 4-5. Recommended technologies for PDA.

Recommended Technology	General Availability Classification	Available Resources
Digital camera	Commonly used	No training needed
Mobile imaging/video logging	Commonly used	No professional training needed
Personal laptops/mobile computers	Commonly used	No professional training needed
Personal communication devices	Commonly used	No professional training needed
Smart devices that embed digital cameras, GPS, and communication	Commonly used	No professional training needed
Personal GPS/GNSS devices	Commonly used	No professional training needed
Digital or paper maps	Commonly used	No professional training needed
Cloth/tape measures/carpenter level/calipers/compass/level/laser distance measures and others	Commonly used	No professional training needed
Signs/marking supplies and materials	Commonly used	No professional training needed
Human visual inspection	Commonly used	*Volume 3: Coding and Marking Guidelines*; FHWA *Highway Bridge Inspection: State-of-the-Practice Survey* (www.fhwa.dot.gov /publications/research /nde/pdfs/01033.pdf)
High water markings	Commonly used	Abboud and Kaiser (2012), Arneson et al. (2012), Huizinga and Waite (1994), Idaho DOT (2004), Pennsylvania DOT (2014)

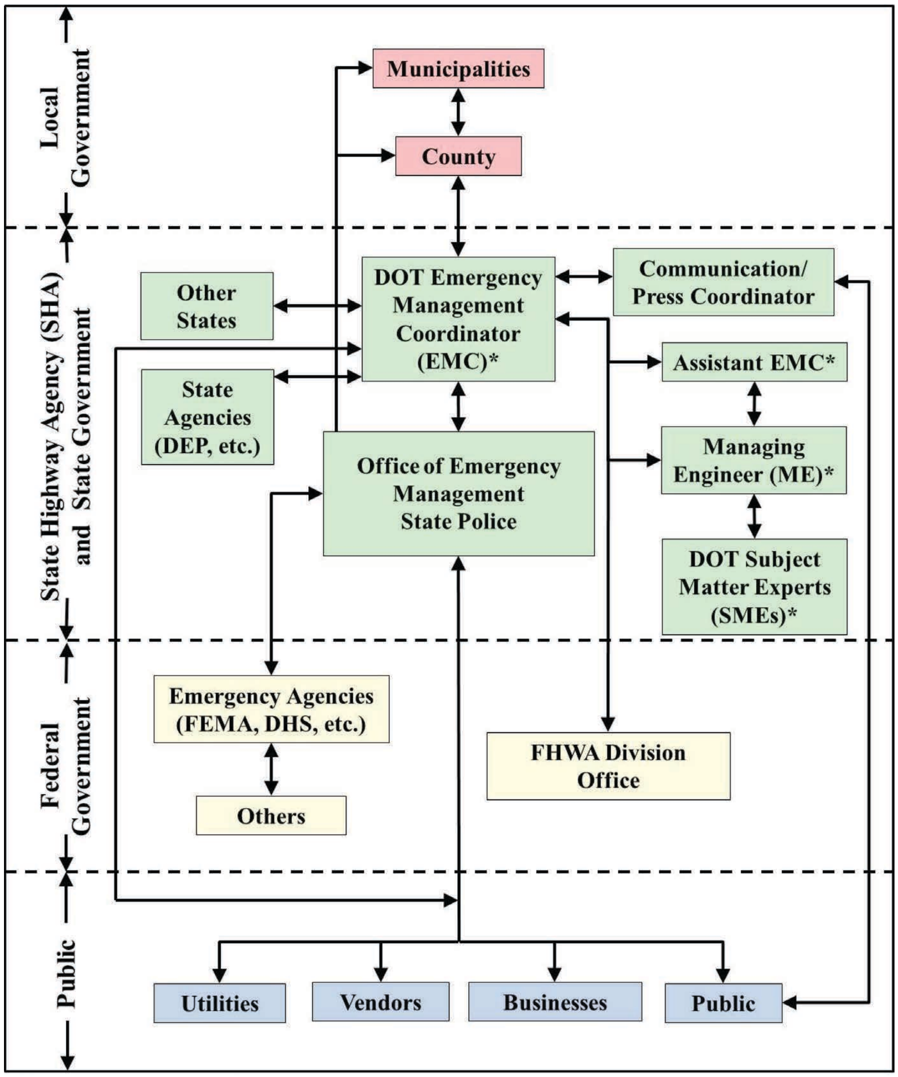
The planned coordination and supporting lines of communication should be well-established, understood, and practiced to the point where they are second nature to all involved parties prior to an emergency event. For the purposes of this section, the coordination effort will consider four tiers:

1. Local government—municipalities and local counties
2. SHA and state government—within the Office of Emergency Management
3. Federal government—government and other agencies
4. Public—vendors and the general public

Table 4-6, along with the flowchart in Figure 4-3, is a summary of the proposed lines of communication and suggested protocols at each of the four tiers. Figure 4-4 also highlights the proposed chain of command within the SHA.

Table 4-6. Table summary of proposed lines of communication and suggested protocols.

Agency and Title		Description
Local Government	Municipalities, Counties, etc.	It is suggested that the same hierarchy as SHAs be implemented, or at least an emergency management coordinator be assigned. Local government involvement is important to the SHAs' timely emergency response.
SHA and State Government	Emergency Management Coordinator (EMC)	The EMC will have responsibility for all coordination and communication in case of an emergency. The EMC needs to have the responsibility for developing an ERP that is best suited to the needs of their particular state. Depending on the size of the state, it may be necessary to have an assistant to this position. Responsible for adopting the suggested "First You Plan" concepts.
	SHA Subject Matter Experts (SMEs)	Chief structural, geotechnical, hydrological, mechanical, and material engineers who specialize in the affected structure types. Report to the managing engineer. SMEs properly apply and follow the procedures derived from the Assessment Process Manual. Approve standard work packets that are developed for the inspection teams including assessing, coding, and marking procedures and information management. SMEs support the chain of command and properly communicate their findings. Contingency plans with what-if scenarios should be presented and explained to increase the likelihood of success. Prepare and coordinate pre-incident planning and training. Provide reference materials.
	Assistant EMC	Reports to the EMC. Properly applies and follows the procedures derived from the Assessment Process Manual. Ensures implementation of the standard work packets that were developed for the inspection teams including assessing, coding, and marking procedures. Assists in establishing the chain of command and how to properly communicate the findings. Contingency plans with what-if scenarios should be presented and explained to increase the likelihood of success.
	Other SHAs	Neighboring states in case of an emergency event crossing state boundaries.
	Communication/ Press Coordinator	Communicates with the public (see Public Entities row). Ensures that procedures are followed per SHA requirements.
Federal Government	FHWA Division Office	Establishes and maintains communication channels within FHWA.
	Emergency Agencies	Lines of communication with federal and state agencies such as FEMA and the Department of Homeland Security need to be identified. SHAs are encouraged to follow the established protocols.
Public Entities	Vendors	Coordinates and places agreements in advance with communication companies, online service providers, and others.
	Public	Coordinates with public. Can take many forms including incoming calls, emails, media reports and queries.



*Refer to Interagency Communications
DEP = Department of Environmental Protection

Figure 4-3. Flowchart of proposed lines of communications.

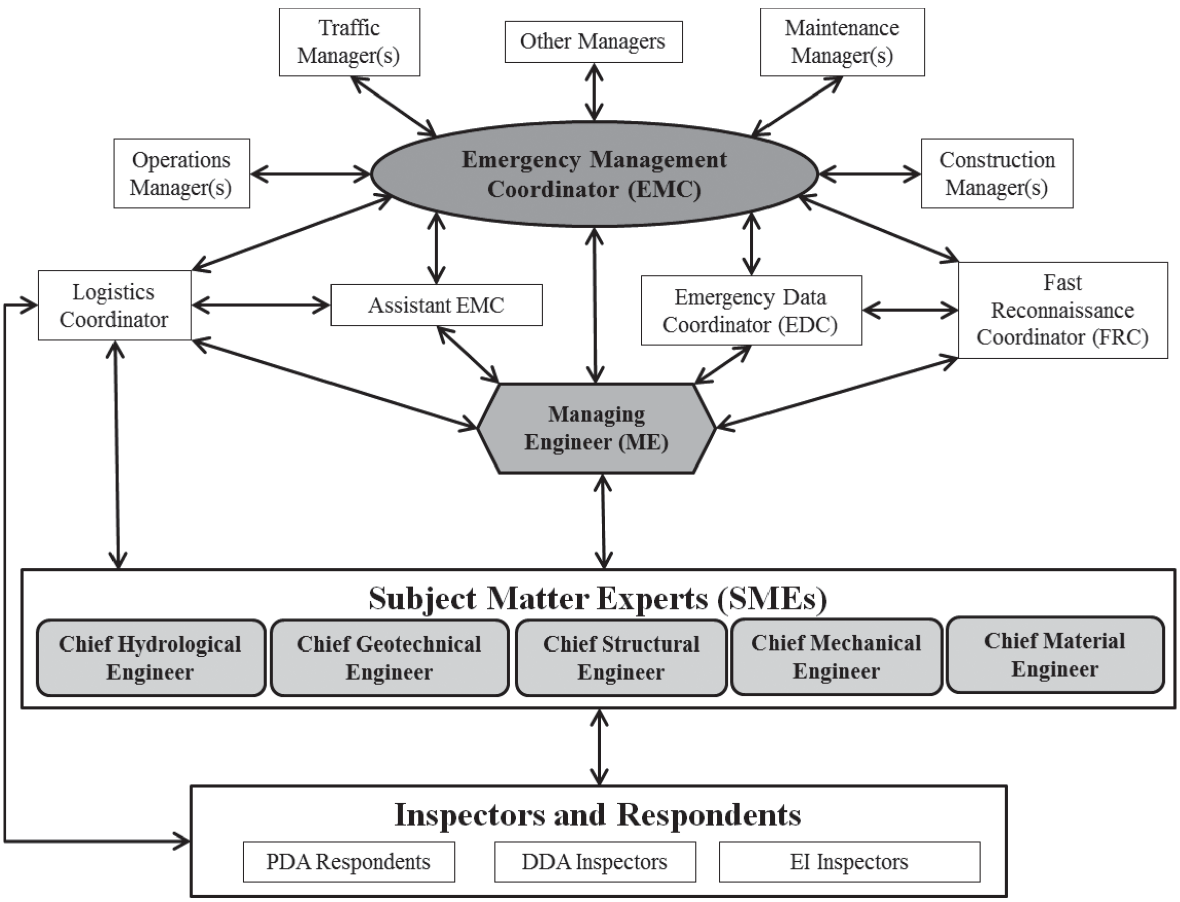


Figure 4-4. Interagency communication chain of command.

CHAPTER 5

Coding and Marking Guidelines

An integral part of the assessment process is to communicate the results via coding and marking. Coding is the process of using a shortened notation or series of letters, numbers, or symbols to indicate the integrity of a structure, its components and elements, and other parameters associated with it. Marking is the process of applying an identifiable code to the structure in order to inform others of its condition. This can be done physically or digitally. The physical marking of a structure is sometimes referred to as "posting."

5.1 Volume 3 Overview

In addition to the Assessment Process Manual described in Chapter 4, a separate field manual was developed and is available as *Volume 3: Coding and Marking Guidelines.* Volume 3 was developed as a flipbook resource for the PDARs to use directly in the field in order to enable rapid yet effective evaluation of highway structures after emergency events. Volume 3 is divided into three parts so as to enable efficient access to information.

Part I of Volume 3 provides concise background information that is helpful for performing evaluations of highway structures during emergency situations. The chapters included in the background are the introduction, overview of highway structure safety evaluation, proposed preliminary damage assessment guidelines, and an overview of emergency events. These chapters should be reviewed prior to conducting evaluations of highway structures.

Part II discusses the specific PDA procedures and considerations for bridges, tunnels, culverts, walls, and overhead signs. Each chapter provides a general overview of the highway structure; a schematic; the PDA procedure; a list of elements; and the damage states that define minor, moderate, and severe damage levels for each element. For each highway structure type, assessment forms are included to be used as reference for collecting damage data during the emergency events. In practice, these forms should be completed digitally with a smart app (See Chapter 6 of this volume) or manually with paper copies [Microsoft Word files of the forms are available on the TRB website (www.trb.org)].

Part III contains example damage photos that can be used to help rate the damage level for each element of the structure. Pictures are included for bridges, tunnels, culverts, walls, and overhead signs, as well as scour. Classification examples are provided for minor, moderate, and severe damage, when applicable. Individual DOTs may wish to adapt these as relevant to their infrastructure and hazards. In some cases, there may not be photos for all three damage states. For these instances, some judgment will be required of the PDAR when selecting a damage rating.

Volume 3 also contains several appendices including equipment lists, field safety considerations, contact list templates, an emergency route template, and an assessment form example. It

is envisioned that each SHA will augment these pages with information specific to their agency so that it is readily available for each PDAR.

5.2 Coding and Marking Process

A coding and marking system was developed to support uniform communication between inspectors, maintenance crews, engineers, and others as necessary. The terms INSPECTED, LIMITED USE, and UNSAFE were chosen to be consistent with the process used for buildings (i.e., ATC-20). The term INSPECTED was selected because many bridges in use today are classified as "structurally deficient." Given that PDAs should take no more than 30 minutes per structure, the assessment is likely not detailed enough to imply any structural capacity other than that the structure appears to be in the same condition as it was prior to the emergency event. To maintain consistency within the whole process, the terms were also used for DDA and EI.

Given the scope and range of damages that can occur from the wide variety of emergency events that are possible across the country, a simplified taxonomy was developed in order to group common forms of damages so that a systematic process could be implemented that is nearly independent of the hazard type as summarized in Section 3.1 of this volume.

All inspected structures within the impacted region should be marked both physically (in the PDA stage) and digitally (in the FR and PDA stages) after an assessment is conducted and the coding for the structures is established. Structures should be marked physically in an obvious location on both ends of major elements of the structure using placards affixed with a color decal of the coding option (see Figure 5-1 for the placard and Figure 5-2 for the coding options). For example, the placard with decal would be on the right-hand side of the approach to the bridge (i.e., on railings or fixed structural elements at both bridge abutments). These posting placards and decals should be available at all offices and in the inspection vehicles.

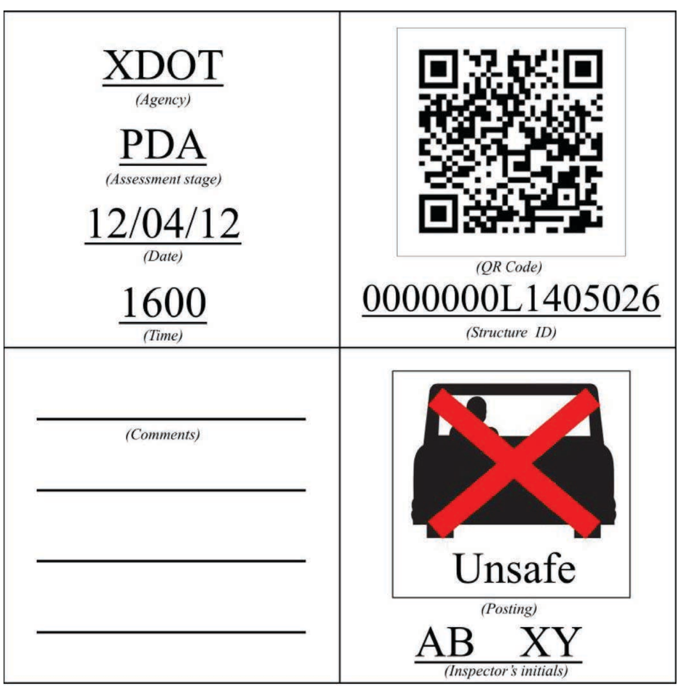


Figure 5-1. Example marking placard.

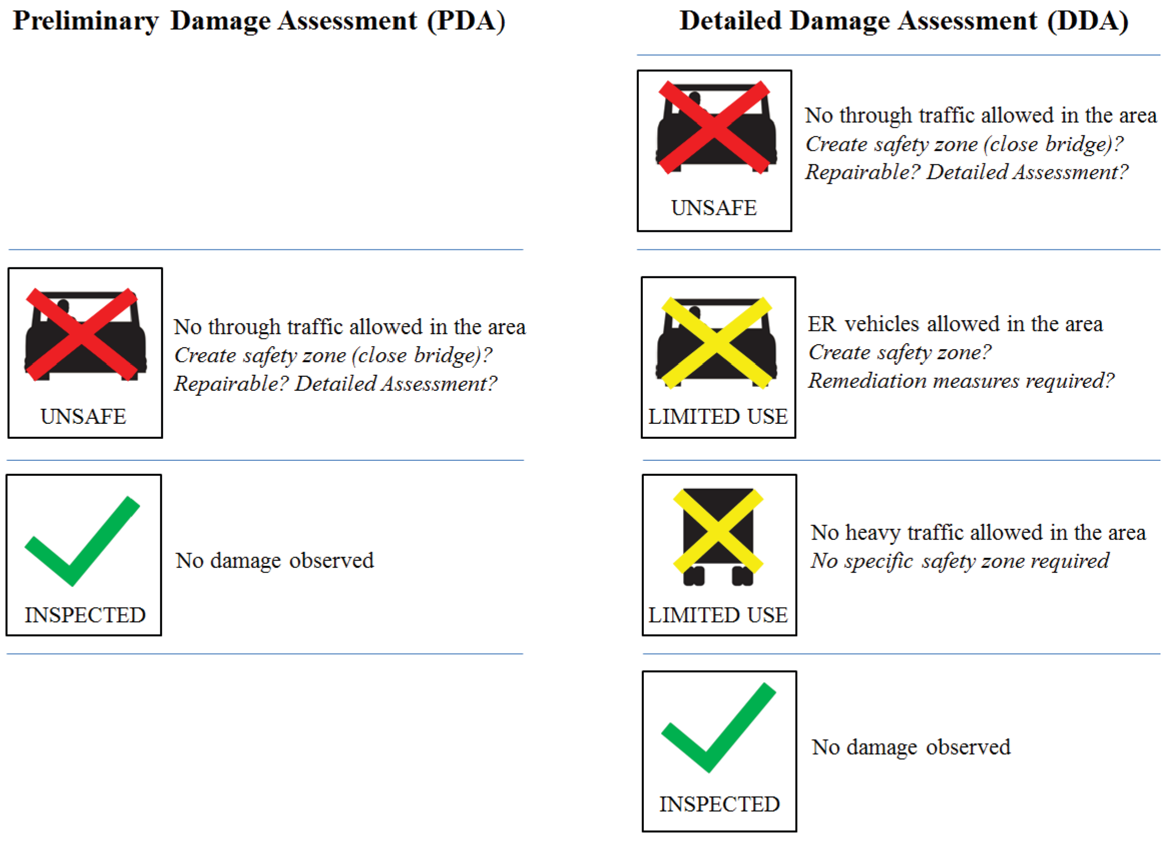


Figure 5-2. Coding options for PDA **(left)** ***and DDA*** **(right)*****. These can be printed as decals to be placed on the placard shown in Figure 5-1.***

Structures should be marked digitally in a central database and/or GIS map that is accessible to authorized staff with a secure connection. The use of QR codes on the placard in concert with smart devices (i.e., smartphones or tablets) or stand-alone readers can significantly reduce coding time and improve information flow and reliability between personnel and across agencies. PDARs should have decals with QR codes or have access to a mobile QR code printing machine. Guidelines on how these should be implemented are discussed in Chapter 6 of this volume.

The marking (and hence contents of the QR codes) must clearly indicate the agency that made the marking, the assessment stage (i.e., PDA or DDA), the date and time of the assessment, the resultant coding (i.e., INSPECTED, LIMITED USE, UNSAFE), actions taken (e.g., close structure, close lane), and initials of the PDAR.

After undergoing PDA, highway structures should be marked with one of two placards: INSPECTED or UNSAFE (refer to Figure 4-1). If a structure is marked UNSAFE during a PDA evaluation, it will be further evaluated using DDA. During DDA, highway structures are marked with one of three decals on a new/updated placard: INSPECTED, LIMITED USE, or UNSAFE (refer to Figure 4-1). This posting lets the SHA, respondents, inspectors, and the public know the condition of the structure as well as the date and time the assessment was performed. The system used for marking a highway structure and the definition of each marking category are summarized in Table 5-1.

In addition to marking a highway structure, it may be necessary to designate restricted use of certain parts of the structure that may be hazardous areas. For example, if a bridge deck is badly cracked or raised on one side, traffic should be redirected onto the non-damaged portion of the bridge.

Table 5-1. Highway structure coding and marking classifications for PDA and DDA.

Marking Classification	Description
INSPECTED (Green)	This classification utilizes a green color code and indicates that, subject to the inspection at the current stage, no apparent damage was found and the pre-event load-carrying capabilities of the structure appear to be fully intact. **No restrictions on use.**
LIMITED USE (Yellow)	This classification utilizes a yellow color code and indicates that dangerous conditions are believed to be present. **Usage is restricted to ensure public safety**. The restrictions to use must be clearly defined by symbols and can include lane closures, vehicle load limits, or use by emergency vehicles only.
UNSAFE (Red)	This classification utilizes a red color code and indicates that extreme hazards are present, the structure is in imminent danger of collapse, or the structure has collapsed. **The structure is closed to all traffic.**

CHAPTER 6

Smart App Development Guidelines

6.1 Background and Motivation

Field inspections can generate a large amount of data including digital images, text-based narratives, voice recordings, and other logged data. Therefore, computer-aided data collection, archival, or even data processing in the field become desirable, which enables rapid data synchronizing and coordination between field crews and office analysts. The latest smart devices, including smart tablets and smartphones, integrate a variety of advanced hardware and software systems for sophisticated multi-functionality. With the basic smart functions including high-quality imaging, geo-tagging, and communication, smart devices tend to replace many conventional single-function mobile devices, such as phones, cameras, laptops, and GPS devices. Therefore, smart devices are ideal equipment for emergency response.

The questionnaire results (see Chapter 2) and feedback from the emergency responders at the state DOTs revealed two important facts, which further motivate the development of smart applications (or "smart apps") as one of the key emergency response technologies. First, the feedback indicates that the majority of respondents (92%) store their structural inventory and assessment data in a digital format based on typical computer servers or workstations. Second, the questionnaire results revealed that, compared with other technologies, smartphones and tablets are given higher priority by the DOTs when responding to emergency events. The two facts imply that SHAs and the professional community are ready and keen to use, and in many cases have used, smart mobile technologies for rapid emergency response.

6.2 Development of Primary Smart App Functions

A technical manual developed in this project provides guidelines for developing a mobile-device-based smart app for PDA responders (PDARs). The manual includes guidelines for developing interfaces, basic functions, and server or cloud-side services to support the smart functions. The complete manual is available as *NCHRP Web-Only Document 223: Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations* on the TRB website (www.trb.org); this chapter summarizes the guidelines.

The envisioned smart app primarily aims to automate the manual and paper-based assessing, coding, and marking procedures, which are described in detail in this volume, *Volume 2: Assessment Process Manual*, and *Volume 3: Coding and Marking Guidelines* of *NCHRP Research Report 833.* The smart app runs on a smart device, which relies on its back-end server for data storing, retrieving, and processing; information retrieval or relay; and providing aggregated

results. Therefore, the resulting smart app is a client–server software system. The manual defines two basic functions for the smart app:

1. Primary function: automating the assessing, coding, and marking (ACM) functions to enhance the efficiency of field-based ACM procedures.
2. Auxiliary function: providing sharing and visualization functions that access aggregated and GIS-based ACM analytics products to the DOTs' management and other emergency response engineers.

A worst-case scenario for using the smart app—no external digital data communication (via neither Wi-Fi Hot Spot nor cellular network) is available to the PDARs in the field—is considered in the manual. In this scenario, smart devices are unable to connect to the Internet and hence to the back-end servers. The software design should consider this worst-case scenario and warrant that PDARs can continue to use their smart devices alone without connecting to the server and then perform ACM in the field. This means that a PDAR can perform ACM based on his/her training, experience, and basic aids such as GPS location services. Once the field data and individual PDAR's coding/marking have access to the Internet, these data can be uploaded and synchronized to the server. Then through a unified analytics service from the server, high-level decision making by the SHA's emergency officials can still be conducted.

The following sections brief the guidelines and present the major illustrations showing the smart app's interfaces.

6.3 General Software Design Guidelines

The guidelines address the following key suggestions for the general software design and development:

- Field operation and data generation workflows
- Data structures
- System architecture and ACM functions

6.3.1 Field Operation and Data Generation Workflows

The purpose of defining the primary operation workflow and the associated data workflow is to prepare a systematic "big picture" for the software engineers who need to understand the basic procedures of the assessing, coding, and marking performed by the PDARs (who are not software engineers) in the field.

6.3.2 Data Structures: Variables, Data, and Interoperability

Field assessment followed by coding and marking, whether paper based or smart app based, involves collecting and logging data into the designed data entry fields. For designing and programming the smart app software, internally a set of global variables need to be defined that await user's input values or retrieved values from existing databases. Many of these variables are hierarchically or causally related. Therefore a data structure that describes the relations of the basic variables that are involved in the PDA procedures is critical. The manual suggests a series of key variables, their values, and more importantly their inherent relations that reconciles the field operation and data generation workflows.

6.3.3 System Architecture and ACM Functions

The system architecture and the primary ACM-related functions of the smart app are suggested in the manual. In Figure 6-1, two software subsystems are shown including the client-side

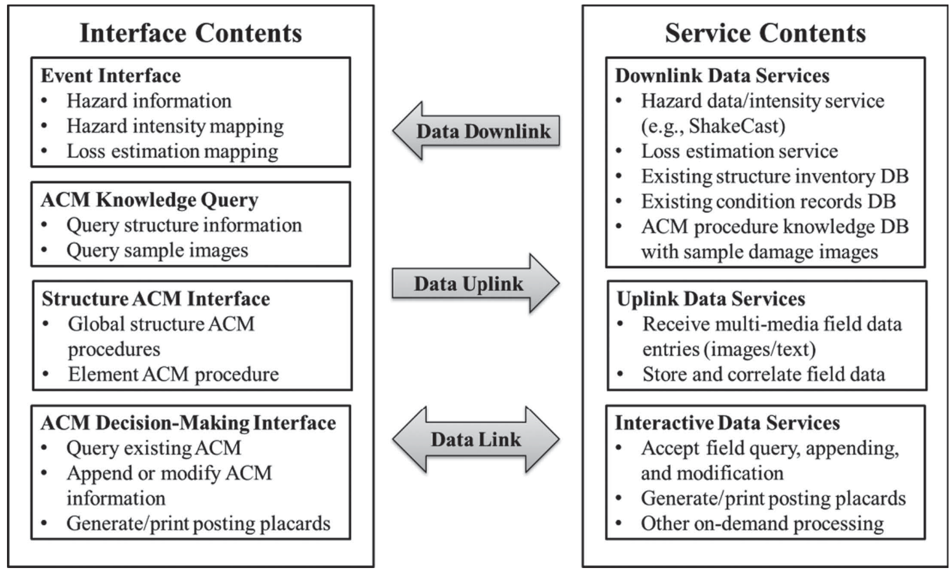


Figure 6-1. Suggested ACM architecture design and basic functions grouped as modules of the smart app system.

(user interface) smart functions and the server-side services. The proposed architecture design in Figure 6-1 suggests the essential functions and services, which are grouped as different modules. For practical implementation, it is up to the software engineers to decide how to group these functions/services in different modules.

6.4 Guidelines for Interface Design

NCHRP Web-Only Document 223 provides recommendations for the major interface design. These major interfaces are listed hierarchically and the major interface illustrations follow:

1. **User Registration and Logging Function:** Provides user registration, login, and ID authentication with services aided by the server.
2. **Main Entry Interface:** Provides a unified interface for initializing the main functions of the app.
3. **Event and Hazard Information Interface:** Provides interfaces for retrieving the event (the emergency), hazard-based data, and disaster response information and an interactive mobile environment that assists the PDAR's on-demand and real-time decision making.
4. **ACM Knowledge Base:** Serves the PDARs who are in the field to assess a structure of interest. The basic design methodology for this interface is suggested as follows:
   – **Structure ACM Interface** (Figure 6-2): Acts to automate the PDA procedures for the global structure and provides an entry point to the element-level ACM interface. The major interface design for this interface includes the following:
      ▪ **Structure Type, Location, and Structure Name** (Figure 6-3)
      ▪ **Structure Information, Predicted Damage, and Overall Damage Description** (Figure 6-4)
      ▪ **Imaging, Annotation, and Sketching** (Figure 6-5)
      ▪ **Coding and Marking** (Figure 6-6)
   – **Element ACM Interface:** Automates the PDA procedures for elements when structures show no obvious patterns or show signs of major damage that is not visible at distance (Figure 6-7)

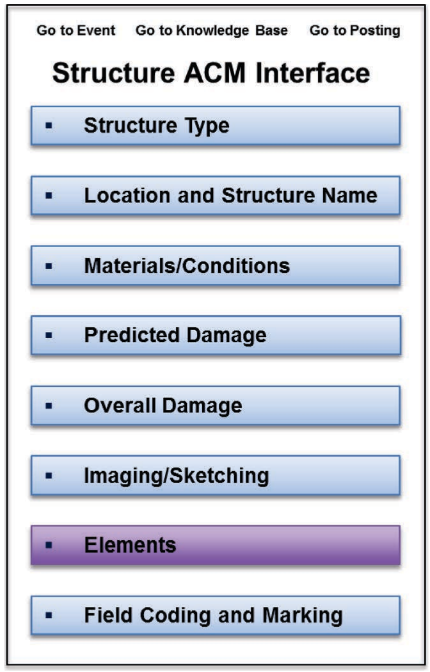


Figure 6-2. Suggested structure ACM main interface with menu items to lower-level interfaces.

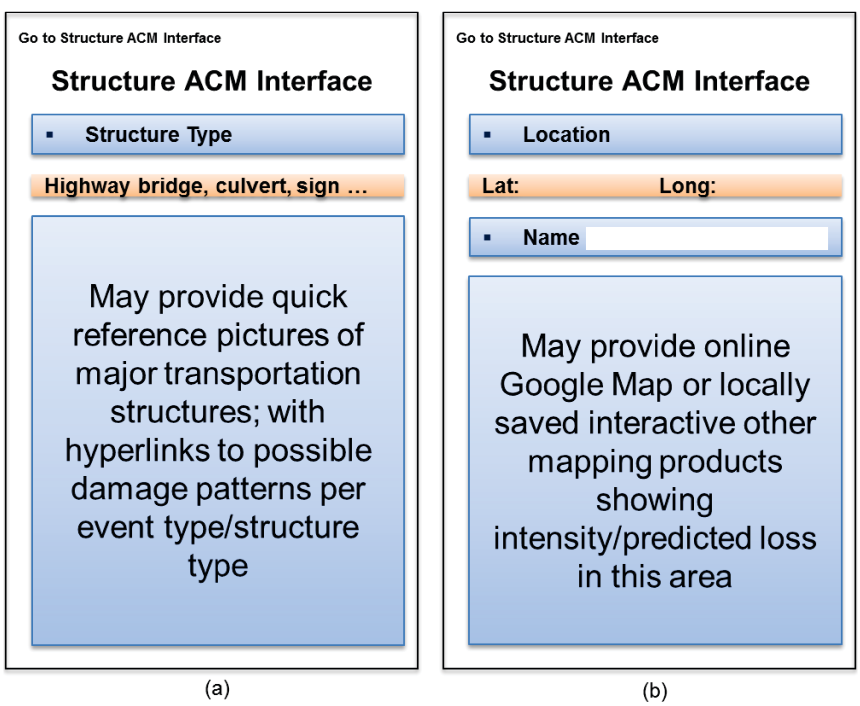


Figure 6-3. Suggested interface design for (a) structure type and (b) location and structure name.

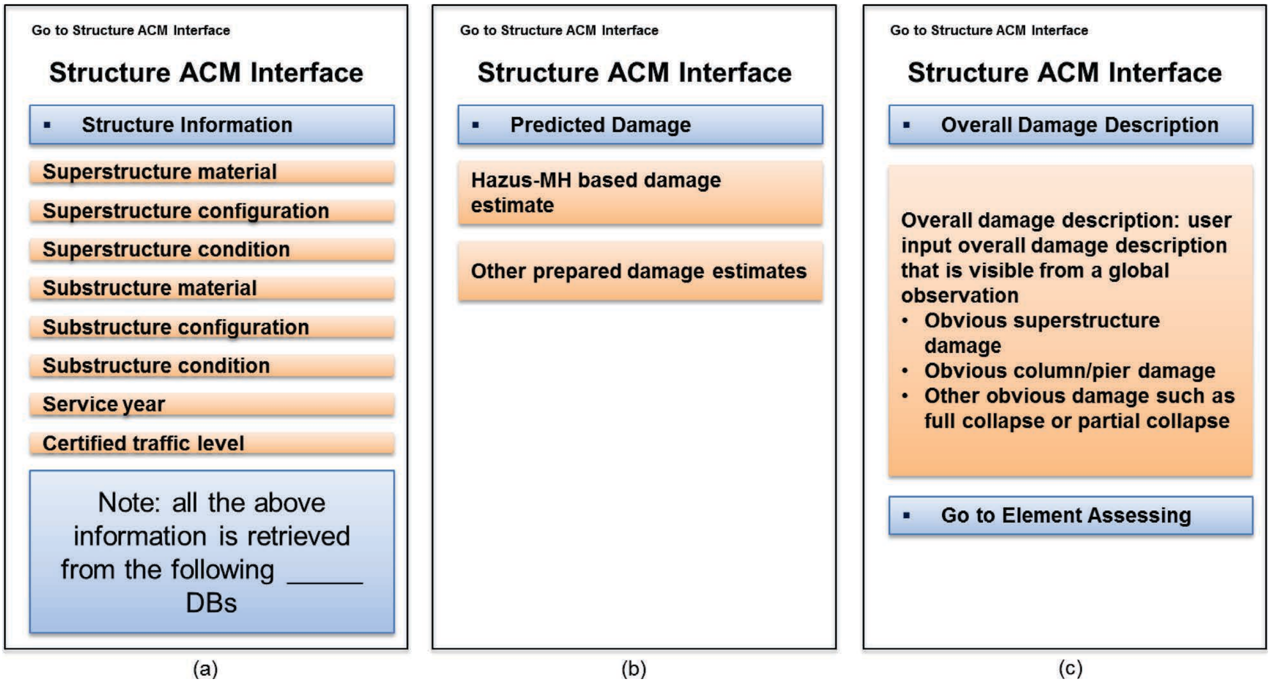


Figure 6-4. Structure ACM interfaces for (a) structure information, (b) predicted damage, and (c) overall damage description.

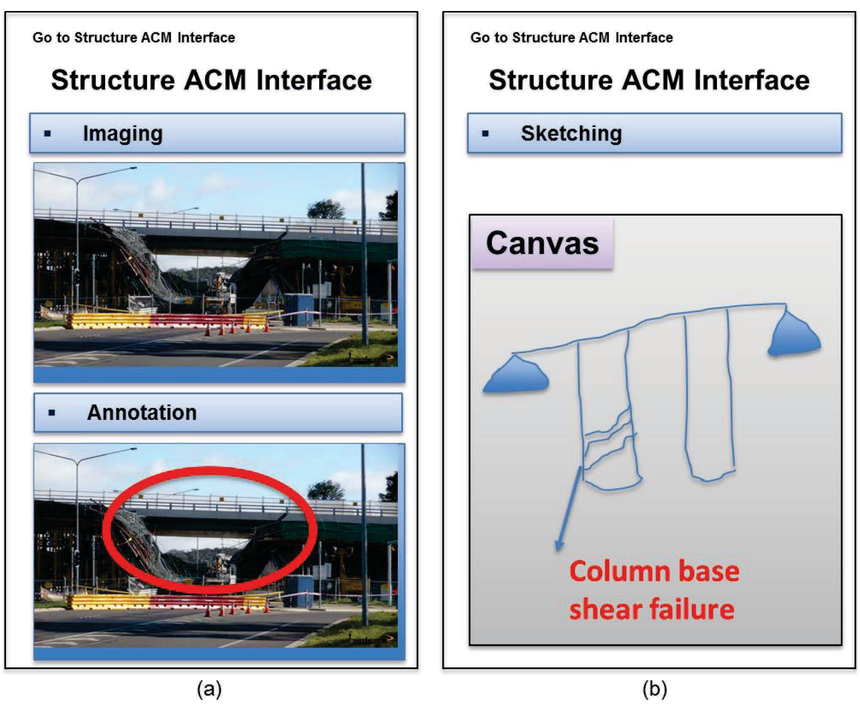


Figure 6-5. Structure ACM interfaces for (a) imaging/annotation and (b) sketching.

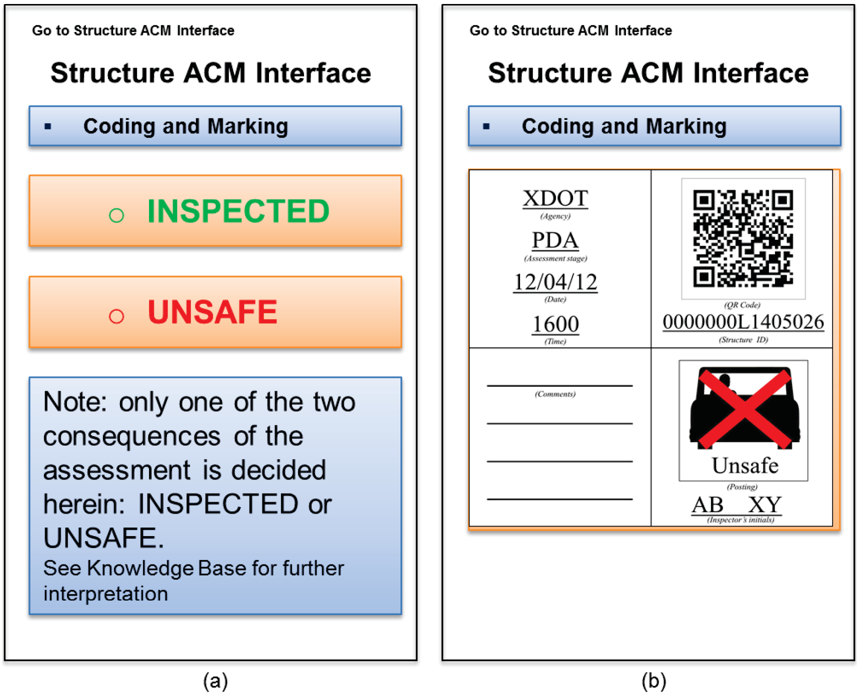


Figure 6-6. Structure ACM interfaces for coding and marking: (a) marking decision and (b) coded placard.

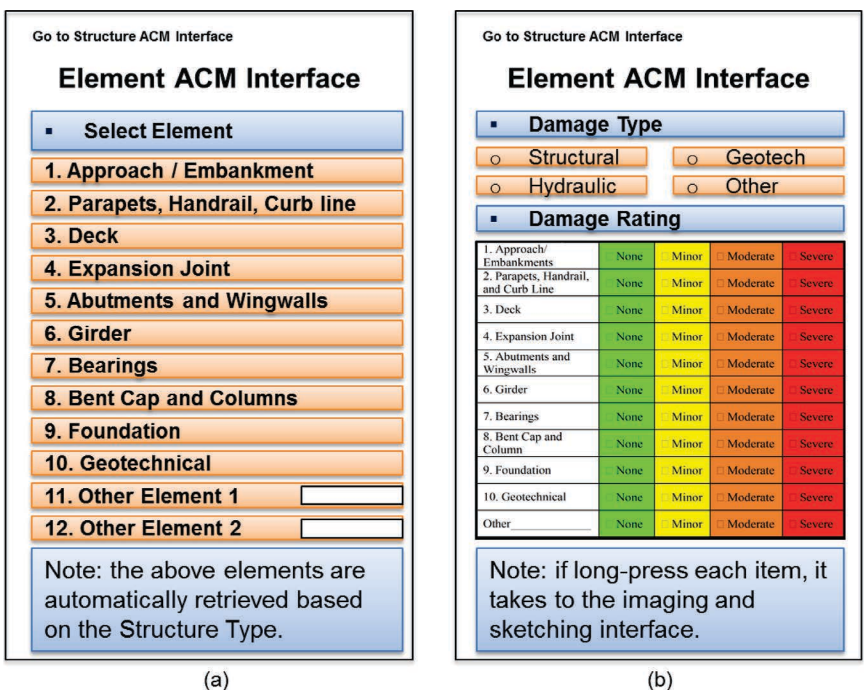


Figure 6-7. Element-level assessment interface: (a) selecting element and (b) element-level damage type and rating that may be further linked to imaging/sketching interface for any element.

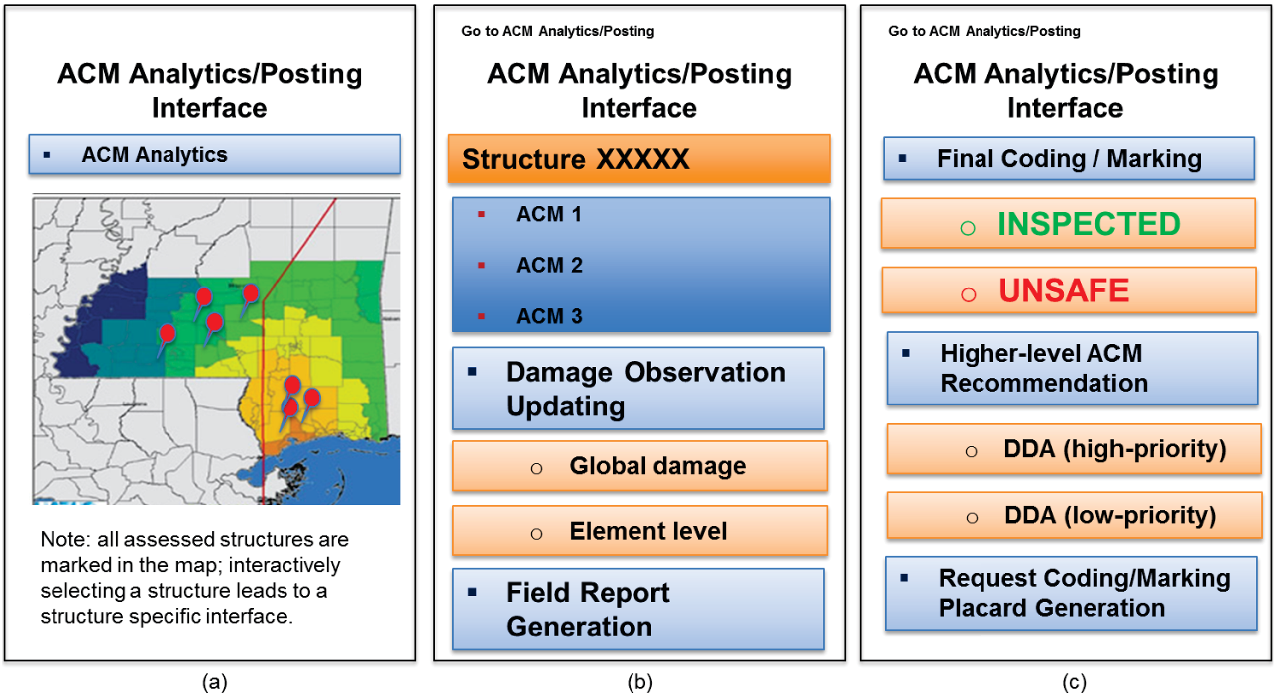


Figure 6-8. ACM Analytics and Posting: (a) aggregated ACM for different structures in a disaster zone; (b) one structure with different ACM results accessible through QR code reading, and damage data for the global structure or the elements, which can be amended (by modifying existing data or adding more observation data); and (c) a consensus for the final coding and marking.

– **ACM Analytics and Posting Decision-Making Interface** (Figure 6-8): Provide both team-based data sharing and a final coding and marking decision-making interface. Figure 6-8(a) shows a sample illustration of the aggregated results of the ACM process from different PDARs for multiple structures.

6.5 Server Design and Services Design

The server development includes design and implementation of critical services that collaboratively realize the functions in the front-end interfaces as shown in the previous sections and figures. As illustrated in Figure 6-1, the basic services grouped based on the directions of the data flow, are as follows:

- **Downlink Data Services** that provide retrievable information for event information, hazard-related mapping products, and other regular mapping products. Downlink data also include structural inventory and condition data per users' query based on the inventory databases and the structure condition records databases. The databases also include an ACM knowledge database, which provides searchable ACM procedures and sample images of all types of damages for transportation structures and element.
- **Uplink Data Services** that handle field data receiving and storing including all the structural ACM data for structures and structural elements.
- **Interactive Data Services** that deal with field query, interactive ACM data appending, modification, PDA report generation, and other on-demand two-way data services.

6.6 Summary

NCHRP Web-Only Document 223 provides guidelines for developing mobile-device-based smart applications for PDARs to use in emergency situations for assessing, coding, and marking transportation structures. Besides the guidelines briefed in this volume of *NCHRP Research Report 833*, *NCHRP Web-Only Document 223* suggests optional smart functions for the app, including voice recognition and recording, peer-to-peer tethering between devices, and cloud-computing-based advanced analysis and data interoperability services. This manual is expected to facilitate communication between structural engineers, PDARs, inspectors, and the IT professionals who will develop and manage the application and associated data; therefore, the resulting smart app would greatly automate the manual and paper-based assessing, coding, and marking procedures.

CHAPTER 7

Training Materials and Recommendations

7.1 Overview

This chapter describes the training materials developed as part of this project. The intent is that these materials will aid implementation of the assessment processes described in *Volume 2: Assessment Process Manual* and *Volume 3: Coding and Marking Guidelines.* The training materials comprise four workshops that tailor content to a specific audience based on their role in the emergency response:

- General Training—created for anyone who needs a basic understanding of the process for assessing, coding, and marking of highway structures in emergency situations.
- Specialized Managing Engineer Training—developed for the managing engineer and subject matter experts.
- Basic PDAR Training—developed for anyone who will be a PDAR including maintenance, design engineers, and other personnel.
- PDAR Quick Refresher—developed for PDARs when an emergency event is imminent or has just occurred.

These training workshops vary in length from 30 minutes to 8 hours and are composed of up to 14 modules. Each module has been prepared as a Microsoft PowerPoint presentation with speaker notes for each slide. Training deliverables include all source PowerPoint files, as well as a set of PDF handouts with speaker notes for each training workshop. Figure 7-1 provides an example of the training module materials. The left side shows an example of the speaker notes provided while the right side highlights six slides and their content.

Additional training resources are provided in *NCHRP Synthesis of Highway Practice 468: Interactive Training for All-Hazards Emergency Planning, Preparation, and Response for Maintenance and Operations Field Personnel.* Although those resources are much broader in scope compared to the training materials developed in this research that focused on structures, it is recommended that training materials from this research be implemented in a framework consistent with the recommendations in *NCHRP Synthesis 468.*

7.2 General Training

All SHA employees should be aware of their state's emergency response plan and their role in emergency response. The General Training workshop can be completed in approximately 1 hour and was designed to provide an overview of the emergency response process for SHA employees, or persons from other organizations, that may be interfacing with the structural assessment process but will not be directly performing PDAs. This module provides a quick summary of the entire process and can be used to foster discussion on how each employee fits in with the overall

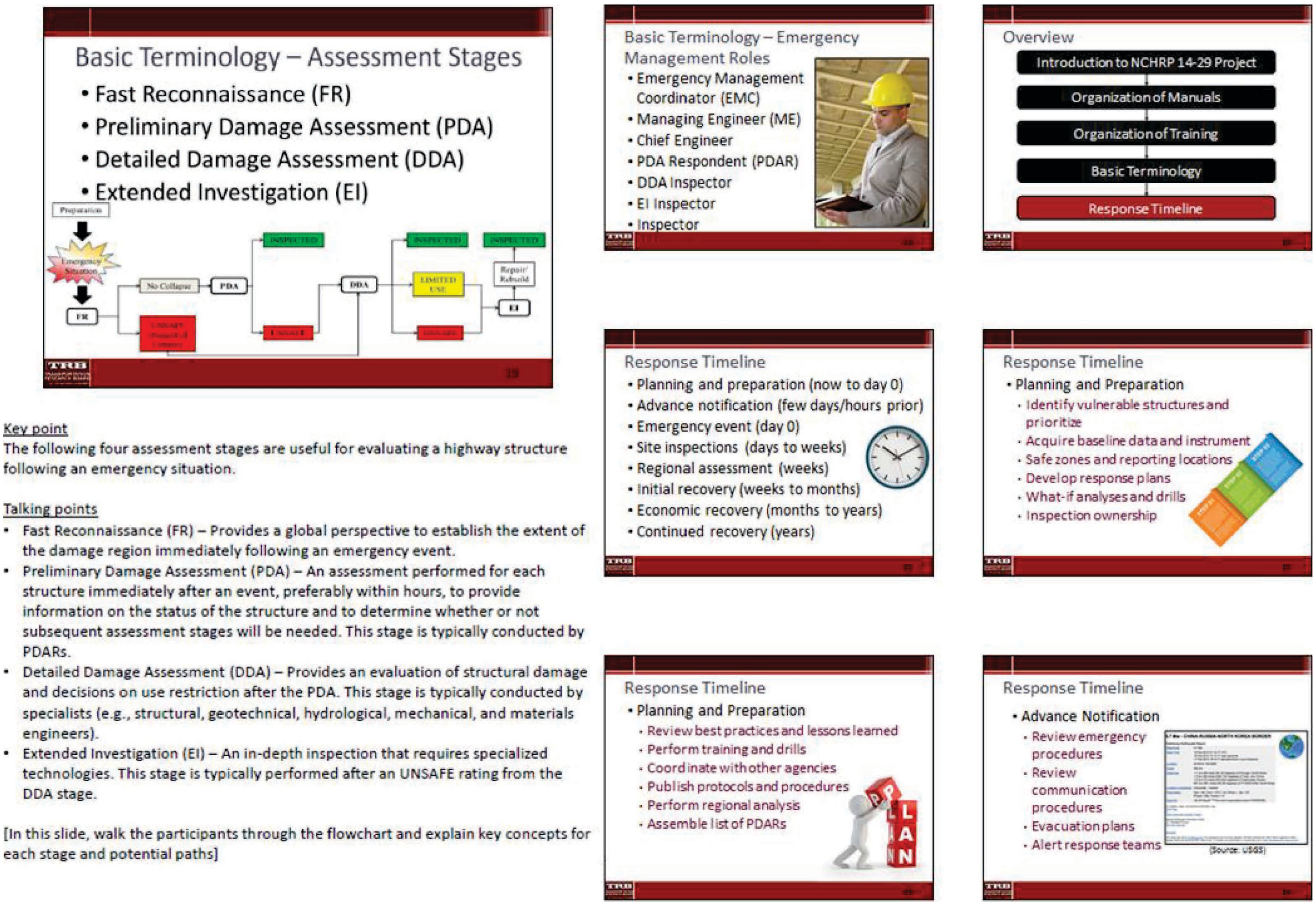


Figure 7-1. Example of training module materials.

emergency response. This workshop is composed of a single module and could be delivered as a webinar to reach a large audience at minimal cost and disruption.

7.3 Specialized Managing Engineer Training

The Managing Engineer Training workshop consists of 13 modules and was designed for managing engineers and those who will be responsible for implementing and overseeing the assessment process within the SHA. The training materials are expected to run nearly 8 hours in total duration and can be presented as a single 1-day workshop or spread across multiple days or weeks.

Table 7-1 presents a sample agenda and learning objectives for each of the modules within the Managing Engineer Training workshop.

7.4 Basic PDAR Training

The PDAR Training workshop consists of 14 modules and was designed for PDARs or those who will be responsible for performing the PDA. The training materials are expected to run approximately 6 hours in total duration and can be presented as a single 1-day workshop or spread across multiple days or weeks.

Table 7-1. Modules available for the Managing Engineer Training.

Module and Title	Estimated Duration	Description	Learning Objectives
Module 1: Overview	30 min.	Presents an introduction to the project and objectives; discusses the organization of the manual, coding and marking guidelines, and training materials. Briefly introduces the topics discussed in each module and presents basic terminology.	• *Be introduced* to *NCHRP Research Report 833: Assessing, Coding, and Marking of Highway Structures in Emergency Situations*. • *Understand* the purpose of – *Volume 2: Assessment Process Manual* – *Volume 3: Coding and Marking Guidelines* – *NCHRP Web-Only Document 223: Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations.* • *Become familiar* with basic terminology used for coding and marking, assessment stages, response levels, element damage ratings, marking classifications, and emergency management roles. • *Review* the response timeline starting from pre-planning stages through years after the event.
Module 2: Emergency Events and Warning Systems	30 min.	Describes basic types of hazards, intensity measures used to describe the hazards, and warning systems that are available for each.	• *Establish* your agency's own damage matrix. • *Update* emergency notification procedures using the provided links and services. • *Identify* and review the applicable emergency events that are likely to occur in your state.
Module 3: Structural Damages	15 min.	Describes types of structural damages that are commonly observed during emergency events.	• *Learn* about – Structural damage – Geotechnical damage – Hydraulic damage – Special case damage.
Module 4: Planning and Preparation	60 min.	Discusses procedures to plan and prepare for emergency event.	• *Review* and refine current planning and preparation procedures. • *Establish* a current and up-to-date database with structure inventory. • *Prepare* what-if scenarios and analysis for applicable emergency events. • *Identify* personnel that should attend training sessions.
Module 5: Assessment Stages	45 min.	Covers each of the assessment stages and describes how they interface with one another.	• *Understand* how each assessment stage works and functions together. • *Understand* the outcomes and goals for – Fast Reconnaissance (FR) – Preliminary Damage Assessment (PDA) – Detailed Damage Assessment (DDA) – Extended Investigation (EI)
Module 6: Response Levels	30 min.	Describes how to determine response levels based on the emergency events and important considerations for mobilizing personnel.	• *Learn* and define the differences between response levels I through IV. • *Become familiar* with different response levels and associated resources to be used for each response. • *Establish* your agency's own response levels for all applicable emergency events.
Module 7: Fast Reconnaissance	30 min.	Describes how to perform FR and tools available such as airborne imagery and crowdsourcing to help with effective, rapid reconnaissance.	• *Become familiar* with objectives and outcomes of FR. • *Identify* personnel who will be in charge of conducting FR following an emergency event. • *Establish* a list of possible FR technologies and methods.
Module 8: Preliminary Damage Assessment	30 min.	Presents an overview of the PDA process and how to coordinate responders for performing PDAs.	• *Understand* the objectives and outcomes of preliminary damage assessments. • *Learn* the PDA process. • *Learn* how to complete the PDA forms for each highway structure.

Table 7-1. (Continued).

Module and Title	Estimated Duration	Description	Learning Objectives
Module 9: Coding and Marking	30 min.	Introduces the placards and decals used in the coding and marking process.	• *Understand* the marking systems and associated marking codes. • *Familiarize* managing engineers with element damage levels and the ratings. • *Review* the elements to be evaluated for each highway structure.
Module 10: Communication and Coordination	30 min.	Discusses protocols and equipment available for communication during emergency events.	• *Identify* coordination command within your agency. • *Identify* personnel to be given key emergency management roles. • *Establish* backup plans for communication in the event that digital communications are unavailable.
Module 11: Technologies and Equipment	30 min.	Provides an overview of technologies used and helpful tips for appropriate technology usage.	• *Identify* useful technologies for FR and PDA. • *Prioritize* field equipment to be used for PDAs. • *Begin* discussions on developing and utilizing a smart app for the PDA process.
Module 12: Exam Materials	60 min.	Provides a set of questions from each of the modules covered in this training.	• *Review* the training modules presented. • *Discuss* important questions and answers. • *Ask* any remaining questions.
Module 13: Conclusion	30 min.	Contains review slides focused on the course learning objectives and most important materials.	• *Review* all training modules presented. • *Discuss* important concepts within each training module. • *Ask* any outstanding or remaining questions.

Table 7-2 presents a sample agenda and learning objectives for each of the modules. While some content is repeated from the managing engineer training, the notes, level of detail, and arrangement of the content has been adapted to better suit the needs of the PDARs. For example, the planning module for the PDAR training is significantly shorter than for the managing engineer training.

7.5 PDAR Quick Refresher Training

This workshop is intended to be delivered after an emergency event has occurred, or once it is clear that an emergency event is imminent, and will be delivered to PDARs who have already completed the full PDAR Training. This training workshop was designed to provide PDARs with a quick refresher of particularly valuable information just prior to performing structure assessments. This module provides information on the PDA background, PDA process, and the coding and marking system within a 30-minute time frame.

7.6 Suggestions for Effective Training

While a variety of training materials were developed in this project, the effectiveness of the training will depend on the instructor's knowledge of the target audience and tailoring the workshop content to suit the needs of the audience. This section provides some suggestions to consider when providing the training workshops described previously.

7.6.1 Frequency of Offering

The frequency of training offerings should be related to the frequency of the dominant emergency events in the state hosting the training and must be balanced with other state highway

Table 7-2. Modules available for the PDAR Training.

Module and Title	Estimated Duration	Description	Learning Objectives
Module 1: Overview	30 min.	Presents an introduction to the project and objectives; discusses the organization of the manual, coding and marking guidelines, and training materials. Briefly introduces the topics discussed in each module and presents basic terminology.	• *Be introduced* to *NCHRP Research Report 833: Assessing, Coding, and Marking of Highway Structures in Emergency Situations*. • *Understand* the purpose of – *Volume 2: Assessment Process Manual* – *Volume 3: Coding and Marking Guidelines* – *NCHRP Web-Only Document 223: Guidelines for Development of Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations.* • *Become familiar* with basic terminology used for coding and marking, assessment stages, response levels, element damage ratings, marking classifications, and emergency management roles. • *Learn* the response timeline starting from pre-planning stages through years after the event.
Module 2: Emergency Events	15 min.	Provides an overview of emergency events.	• *Establish* your agency's own damage matrix. • *Identify* and review the applicable emergency events that are likely to occur in your state. • *Review* emergency event metrics.
Module 3: Structural Damages	30 min.	Describes types of structural damages that are commonly observed during emergency events.	• *Learn* about – Structural damage – Geotechnical damage – Hydraulic damage – Special case damage.
Module 4: Planning and Preparation	15 min.	Discusses procedures to plan and prepare for emergency event.	• *Review* and refine current planning and preparation procedures. • *Establish* field safety procedures. • *Identify* personnel that should attend training sessions.
Module 5: Assessment Stages	30 min.	Covers each of the assessment stages and describes how they interface with one another.	• *Understand* how each assessment stage works and functions together. • *Understand* the outcomes and goals for – Fast Reconnaissance (FR) – Preliminary Damage Assessment (PDA) – Detailed Damage Assessment (DDA) – Extended Investigation (EI).
Module 6: Response Levels	15 min.	Describes how to determine response levels based on the emergency events and important considerations for mobilizing personnel.	• *Learn* and define the differences between response levels I through IV. • *Become familiar* with different response levels and associated resources to be used for each response. • *Establish* your agency's own response levels for all applicable emergency events.
Module 7: Fast Reconnaissance	15 min.	Describes how to perform FR and tools available such as airborne imagery and crowdsourcing to help with effective, rapid reconnaissance.	• *Become familiar* with objectives and outcomes of FR. • *Review* the reconnaissance process.
Module 8: Preliminary Damage Assessment	45 min.	Presents an overview of the PDA process and how to perform PDAs on highway structures.	• *Review* the objectives and outcomes of PDAs. • *Learn* the PDA process. • *Learn* how to complete the PDA forms for each highway structure.
Module 9: Coding and Marking	45 min.	Introduces the placards and decals used in the coding and marking process.	• *Understand* the marking systems and associated marking codes. • *Become familiar* with element damage levels and the ratings. • *Review* the elements to be evaluated for each highway structure.

Table 7-2. (Continued).

Module and Title	Estimated Duration	Description	Learning Objectives
Module 10: Communication and Coordination	15 min.	Provides information on communication and coordination during emergency events.	• *Identify* coordination command within your agency. • *Establish* backup plans for communication in the event that digital communications are unavailable.
Module 11: Technologies and Equipment	30 min.	Provides an overview of technologies used and helpful tips for appropriate technology usage.	• *Identify* useful technologies for FR and PDA. • *Prioritize* field equipment to be used for PDAs. • *Begin* discussions on developing and utilizing a smart app for the PDA process.
Module 12: Case Studies	30 min.	Provides several case studies highlighting damage types and severity.	• *Become familiar with* examples of damage types. • *Gain insight* to reasoning behind component ratings.
Module 13: Exam Materials	60 min.	Provides a set of questions from each of the modules covered for this training.	• *Review* the training modules presented. • *Discuss* important questions and answers. • *Ask* any remaining questions.
Module 14: Conclusion	30 min.	Contains review slides focused on the course learning objectives and most important materials.	• *Review* all training modules presented. • *Discuss* important concepts within each training module. • *Ask* any outstanding or remaining questions.

priorities. Workshops should be offered at least once a year for General Training and Managing Engineer Training and at least every 3 years for PDAR Training. However, given the number of people who may need training, workshop organizers should consider offering the training more frequently to create some flexibility for the attendees and ensure that the training does not interfere with day-to-day priorities of the SHA. In addition, workshop organizers should consider integrating the training with regular planning meetings. For example, management could meet to discuss progress on emergency preparations and take a portion of the meeting for training.

While the training materials developed for this project have been designed to be delivered in a single day if participants are geographically dispersed or have other challenges that make it difficult to meet frequently, it may be difficult to digest all the content in a single sitting. Thus, instructors should consider breaking the training workshops up into shorter sessions spread out over 1 or 2 weeks. This approach may allow participants to reflect on the material and allow instructors the opportunity to highlight important concepts several times over the duration of the workshop.

It is recommended that each SHA have a single person responsible for organizing and coordinating the various training workshops for the whole state. Depending on the size of the SHA, this person may organize all of the workshops themselves or they may delegate this responsibility to someone in each region or district of the state. The workshop organizer is responsible for ensuring the instructors for each workshop have the appropriate background and qualifications and that all SHA employees in their region are properly trained.

7.6.2 Instructor

Speaker notes are provided on each slide in each presentation to assist the instructor with key ideas and talking points. Best practices indicate that instructors must be well prepared and able to instantly recall the talking points on each slide using their own words, and that instructors should avoid reading the speaker notes verbatim. This will ensure the instructor is fully engaged in the material and will go a long way in maintaining the focus of the audience.

Another option that may help maintain the audience's attention is to have multiple instructors deliver the content. For example, in delivering the PDAR Training workshop, various managing engineers can present individual modules of the training or experienced attendees can be asked to deliver a portion of the content. This approach will ensure that different voices, presentation styles, and perspectives are brought to each workshop.

7.6.3 Training Duration and Content

A common rule of thumb to gauge the duration of a presentation is to estimate 1 minute for each slide (not including title slides). Based on this rule of thumb, several of the modules may run longer than the estimated duration indicated previously and on the title slide for the module. This is because the intention of these modules was to provide sufficient content to accommodate a variety of backgrounds and to allow the instructor the discretion to select the material that is most appropriate for their particular audience. The research team recommends that instructors select material based on the key learning objectives of each module and their knowledge of the needs of their audience and their SHA.

Some content in the modules are placeholders or examples from other SHAs. These training modules will be much more effective if the instructor tailors the modules and replace these examples with similar content that is specific to the region. For example, a peak ground acceleration map of the state of Oregon is of interest in Oregon but may not be of interest if the workshop is for SHA employees in New York; therefore, a map of New York should be used instead. Similarly, it is recommended that instructors tailor the modules by focusing on the hazards that are most likely to occur in their region.

To maximize the impact of the workshop, instructors should provide training materials, such as slide handouts, to attendees a few days prior to the workshop and encourage attendees to review the material. In addition, instructors should bring training material to the workshop and ensure that attendees have material to take home to review at their leisure. Alternatively the material can be posted online and accessible at all times by all SHA employees.

Instructors should consider using a few minutes in the training workshops to discuss where their SHA is with regard to the various stages of emergency event planning and preparation. These training workshops are a good opportunity to reflect on what preparations have been completed since the previous training session and to identify emergency response priorities for the next year.

7.6.4 Interactive Discussion

Best practices clearly indicate that training workshops have the most impact when attendees are actively engaged. Suggested active learning techniques include the following:

- Repeatedly encouraging participants to ask questions
- Allowing members of the audience to have the first chance at answering some of the questions asked, rather than the instructor immediately answering the question
- Dividing participants into small groups of three or four to discuss important content and have each small group report back to the full workshop
- Using case studies and handouts that participants must complete during the workshop to foster discussion
- Strategically using quizzes with a discussion of the answers to ensure participants have mastered important concepts and that their responsibilities during an emergency event are clear

While active participation and discussion is critical to a successful workshop, instructors should be mindful of the module objectives and should not allow side discussions or tangents that have little relevance to dominate valuable workshop time.

The training modules developed are scalable and can be effective for both large and small groups. However it is recommended that the workshops be organized for groups of 20 to 30 at a time. This size is optimal because it ensures a critical mass for discussion and is not too large that attendees shy away from participating or become disengaged.

Furthermore, these training workshops should be viewed as an opportunity for team building. One way to foster teams is to select training groups such that attendees who are likely to be paired together in an emergency response attend the same workshop. In addition, organizers should consider inviting representatives from other relevant agencies to attend training workshops. This will allow attendees from different agencies, who are likely to be working together during an emergency event, to meet and interact in a more controlled setting.

7.6.5 Special Activities

Training workshops are critical to properly preparing SHA employees for an emergency event. However, the procedures and guidelines described in the training workshops are likely to be more successful if they are part of a broader training strategy that includes one or both of the following activities:

- **Impromptu Field Trip**—This is an unplanned field trip to a highway structure for an assessment. This periodic activity will help reinforce the concept that emergency events can happen at any time and often require SHA employees to drop what they are doing to respond. It is important to note that this technique should be used sparingly and timed strategically so that it does not disrupt day-to-day SHA operations and does not require significant resources to implement. An appropriate time for this activity may be a week or two after a training workshop has ended to test if participants recall their training.
- **Simulated Emergency Event**—This is a practice drill that is staged at a random time during the year when participants are not expecting it and is an opportunity for SHA employees to practice what they are supposed to do immediately following an emergency event. This drill can also be used as an active learning technique during a training workshop to foster discussion. This drill is likely most effective for events that occur with little or no warning, such as an earthquake, a tsunami, or a tornado and does not need to be longer than 30 minutes. When used effectively, this activity can be a wake-up call that highlights the importance of the training.

7.7 Additional Resources

A variety of emergency response agencies provide training and other resources that may be useful to organizers and participants alike. These include, but are not limited to:

- FEMA National Training and Education (training.fema.gov/)—provides a variety of courses in both preparedness and response; includes a Center for Domestic Preparedness (cdp.dhs.gov/), Emergency Management Institute (training.fema.gov/EMI), and National Training and Education Division (www.firstrespondertraining.gov/content.do).
- ATC (www.atcouncil.org/)—periodic offerings of webinars, workshops, and seminars on a variety of topics.
- American Society of Civil Engineers Infrastructure Resilience Division (www.asce.org/infrastructure-resilience?/infrastructure-resilience-division/)—newly formed committee that is developing resources for disaster assessments.
- FEMA NIMS (training.fema.gov/nims/)—provides online courses related to NIMS. The most important for SHA employees is likely Introduction to Incident Command System, ICS-100 (course code IS-100.B), and National Incident Management System, An Introduction (course code IS-700.A).

CHAPTER 8

Implementation Plan

8.1 Intent

This chapter is intended to provide an overview of the critical factors that need to be considered when incorporating the recommended assessment process and the accompanying guidelines for coding and marking of highway structures during emergency events into an SHA's standard operating procedures. To realize the full potential of establishing these uniform methods, a number of organizational issues need to be addressed. This plan will act as a guide to the implementation process across the entire agency as well as with the other emergency response groups at the federal level and in each state.

8.2 Background

8.2.1 More with Less

Transportation agencies in the United States are experiencing significant reductions in funding while at the same time being asked to improve the level of service that they provide the traveling public. This situation is highlighted during an emergency event. Whether it is a natural or man-made disaster, in today's "mobile app" and "social network" world, everyone expects immediate or even real-time information and response. As seen with some of the recent major storm events such as Hurricane Sandy, this can be a tremendous challenge with the potential for dire consequences to occur.

A few SHAs have adopted processes for the assessing, coding, and marking of highway structures in the event of emergencies. However, these processes do not provide a uniform means for conducting these assessments, or a common method of coding and marking across all U.S. transportation agencies. Also, these processes do not generally address the different highway structure types, the full range of emergency events, or the range of traffic levels. In addition, many of these processes do not explicitly consider the practices of other organizations that often respond to such emergencies with support and assistance.

8.2.2 First You Plan

The guiding principle for this project is "First You Plan." Encouraging this approach establishes pre-emergency event planning as the top priority within a transportation agency with regard to emergency response. If all of the stakeholders, including the traveling public, understand that investing in pre-event planning is required in order to streamline the operational plans and test the lines of communication, then many of the problems can be identified and addressed prior to an actual event.

An integral part of the "First You Plan" strategy is the recommendation to assign ownership of each structure and highway segment within the state to an individual at the local level who has knowledge of the day-to-day performance of the structure in question. Given this responsibility, over time this person can develop an in-depth working knowledge of the condition of the structure during a range of weather and traffic conditions. This will support a more knowledgeable and efficient inspection process as compared to someone visiting the structure for the first time under emergency conditions. Since much of the early inspections are visual, these local individuals will not require a high level of training or expertise in order to be of great value. The assigned person should consider training a backup in case the primary person is not available for any reason.

8.2.3 Organizational Change

To take full advantage of the recommendations contained in this report, many transportation agencies will have to modify their standard operating procedures for emergency response. Most organizations and people by their nature are resistant to change. The larger the organization, the more difficult (and potentially costly) this can be. However, the "no change" alternative may be the most costly option in the long run, particularly if the emergency response programs are out of date or, in some cases, do not exist.

As noted previously, this research was intended to establish uniform processes for conducting structural assessments and to create guidelines for coding and marking structures that can be recognized and adopted by highway agencies and all other organizations that respond to such emergencies. By establishing a national set of processes, all of the transportation agencies will have access to the same knowledge base regardless of their size. This will hopefully lead to a flattening of the learning curve and more confidence in making the organizational changes needed to improve the emergency response procedures. This report has been formatted to encourage the adoption of this methodology on a national scale, perhaps through the support of AASHTO.

The implementation of any new methodology with this level of importance requires the support of senior management in order to encourage the staff to take the required, reasonable risks associated with modifying the standard operating procedures. Introducing a new methodology requires both technical and organizational leadership—a "team of two" as some have described it.

To get the most out of a new methodology, often the business process has to be re-engineered. The staff involved in this process must be encouraged to take risks and be allowed to learn by doing. It is a natural part of the transformational process to make mistakes. The key is to manage everyone's expectations as progressive improvements are made and to communicate the results.

Managing business process re-engineering is not for everyone. There is no one size that fits all. To increase the likelihood of success, each organization must identify early those individuals who tend to thrive in this kind of environment and nurture them to demonstrate the benefits of the new methodology. It will require a team effort along with the support of senior management to implement the new methods.

8.3 Strategic Plan

Before discussing specific recommendations for implementing these procedures and guidelines, the research team would like to briefly discuss the issue of developing a strategic plan to guide the transition. The power of strategic planning comes in the ability to reach consensus on how an organization will look in the future and then working back to the present to identify and prioritize the changes that need to be made.

A major challenge in the development of the required emergency response strategic plan is the coordination that is going to be required with external entities, including the public. It is essential that the plan be coordinated with all appropriate agencies and other states in the region taking into consideration the needs of the traveling public. This will have an impact on the implementation plan; therefore, the two must be developed in harmony and preferably updated on an annual basis.

Selecting and appointing the key people responsible for the plan's implementation early in the process will demonstrate commitment, create buy-in, establish ownership, and provide leadership.

Another critical component that has been discussed previously is data management. In many respects, a strategic plan for emergency management in a transportation agency is largely about data and its integration with many of the key workflows that support emergency response. This will become even more important as the use of mobile computing increases. Transportation agencies can reap significant benefits as they become more mobile data driven in many areas of operation.

8.4 Innovation Group

One strategy that is being used with success at some transportation agencies is the concept of an "innovation group." This group's focus and responsibility is to manage new methodologies/technologies and the change associated with their introduction into an organization. Generally this group is made up of progressive individuals from a number of departments within the transportation agency.

By placing the responsibility for evaluating and introducing new methodologies with an innovation group, senior management and vendors can better manage the process. For this group, technology evaluation and adoption is their primary focus and responsibility. They can develop a set of standard procedures for evaluating new methodologies/technologies and decide how best to introduce them into their organization.

As mentioned earlier, this group must have permission to learn by doing. All pilot projects will not be a success. This is where the support of management and the ability of the group to demonstrate the return on investment in new methodologies/technologies are critical.

The FHWA's Every Day Counts program is focused on innovation. One of the programs to emerge from this effort is the State Transportation Innovation Councils (STICs) (FHWA 2015). The STICs are reporting significant progress in identifying and implementing innovative methods and technologies across the United States. Funding is available from the FHWA for projects that the STICs identify as being important to their state.

8.5 Implementing the Processes and Guidelines

The successful introduction of these processes and guidelines within a transportation agency depends on a number of technical and organizational factors. It is not as simple as replacing the current methods with a new set of published procedures. No matter how much pre-event planning is invested, there will always be unknowns. It will always be difficult to predict how the emergency event is going to impact the structures, the access routes, and the communication networks, which is why the implementation is so critical to success.

The assessment procedures and coding/marking guidelines detailed in this report represent the best practices currently available for emergency response, but at the same time the research team

recognizes that each state may have the need to make changes. One of the primary potential benefits of adopting a uniform approach is that, if an event involves multiple states, coordination of the response will be much easier if the same procedures are being used throughout the country. States are urged to consider this during implementation.

As noted in the previous section, if an innovation or long-range planning group is available, it would be the likely candidate to develop and manage this implementation plan. This group could start by developing a strategic plan that all of the key stakeholders can review and ultimately agree to. There must be a clear, top-down mandate establishing the new methods as the new standard operating procedures.

The innovation group should then decide how best to communicate the plan to all involved parties, including the public. This could involve the development of a website that could support both internal and external information sharing as well as the actual inspection, coding, marking, and reporting.

Once a strategic plan has been developed, one of the best methods for introducing a new methodology is to use a pilot, or series of relatively small demonstration projects, to better understand what is involved. This report discusses the need for the use of regular mock events to identify the issues related to implementing these procedures as well as the training required under real-world conditions. These should be part of a phased implementation strategy.

Once again it is worth mentioning the concept of the "team of two." The most successful technology implementations typically involve someone who is responsible for managing the technical issues and someone who is managing the organizational side.

As noted in a previous section, a coordinated staff training program is essential to the success of the implementation of these methods and guidelines. A detailed training manual has been prepared to facilitate this ongoing process.

8.6 Documenting Results

It is always a challenge to take the time to meticulously document the results of the introduction of a new methodology or program, but this can prevent others from making the same mistakes and create an important set of "lessons learned." Sharing results of lessons learned from implementing this assessment process and coding and marking guidelines will be of high value to the community. In addition, new insights are learned with each event that are important to document so they can be implemented in the future. A related report, *NCHRP Synthesis 446: Use of Advanced Geospatial Data, Tools, Technologies, and Information in Department of Transportation Projects*, shows documented lessons are in short supply for transportation agencies but would be of great benefit.

Once again, this brings up the issue of being allowed to learn by doing. In fact it can be said that setbacks should be expected, even planned for. In many cases, those involved learn more from failures than when the projects "seem" to be going along smoothly. The level of documentation will vary with the complexity of the project, but in general the more detail of the process, the better.

Assuming the initial demonstration projects are documented, it is equally important to publish the results to a larger audience. This can be a challenge when the project has problems, but as discussed, others can learn from mistakes. At the very least, the project documentation should be available within the transportation agency, if not to the entire transportation community.

8.7 Workflow Integration

The final step in the implementation plan will be to integrate the new methods and guidelines into the standard operations of the agency. It may take 6 to 12 months before the key people have been identified, the new methods have been agreed upon, the training and mock events conducted, and all of the potential integration issues, both internal and external, are addressed.

The challenge with the integration is that responding to an emergency event is not part of the normal operations of a transportation agency, at least not on a regional or larger scale. This makes it difficult to gain the experience that in many cases can only come from doing. There is only so much that training courses and meetings can accomplish, but at the same time these are needed to maintain a proper state of readiness. It will be up to the leadership team to determine the proper level of contingency planning, training, and education that makes sense for their agency.

It would also be important to further study whether the developed process can enable more streamlined collaboration across borders of states to avoid inconsistent data analysis and reporting caused by human factors or poorly coordinated data collection and processing workflows.

On a final note, it is important to encourage all members of the response team to provide their input and feedback on the methods and procedures being employed. The people closest to the work will have the best opportunity to provide this valuable insight. At the same time, there will be the need to maintain a uniform approach.

8.8 Future Opportunities

Transportation agencies are transitioning from analogue to digital/mobile workflows. These workflows include the assessing, coding, and marking of highway structures during emergency events. Significant changes in the standard operating procedures of many of the agencies will be disruptive, but at the same time, it is an opportunity to increase productivity as well as the overall quality of services that transportation agencies can provide. This is certainly true with respect to emergency response where, if it is properly planned and organized, the traveling public can become a valuable source of real-time information, and mobile computing can significantly improve the level of communication and data processing.

As noted previously, the FHWA is encouraging transportation agencies to be more innovative through their Every Day Counts initiative. The program is "designed to identify and deploy innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment." For example, research is in progress to design highway structures that use new construction materials (including self-healing materials) and monitoring/inspection methods that are more sustainable and can work with a wider variety of environmental conditions to provide increased safety for the traveling public. Therefore, transportation agencies are going to be presented with the opportunity in the next decade to make use of a number of exciting emerging technologies to better respond to emergency events. This will include mobile computing, wearable computers, UAVs, three-dimensional laser scanning, satellite communications, real-time instrumentation, smart materials, and many technologies that are currently in research labs.

Finally, transportation agencies are well positioned to drive improvements in new technologies and methods. Agencies represent an important market segment for hardware and software vendors. Most of the current technologies are in their first generation. There is significant opportunity to improve the ease of use, the level of systems integration, and data interoperability going forward.

CHAPTER 9

Conclusions and Future Outlook

This report provides guidance to help ensure a highly coordinated and efficient workflow for the assessing, coding, and marking of highway structures in response to a wide range of emergency events. The recommended methodology was designed to be practical and flexible so that it can be implemented by a wide range of SHAs while still establishing uniform best practices across the United States.

To ensure an efficient assessment process that optimally allocates resources, a multi-tiered approach with appropriate redundancy was designed. The strategy is grounded in frequent planning and preparation efforts (First You Plan) supported by the appropriate responder training. The assessing, coding, and marking processes were subdivided into four stages: Fast Reconnaissance, Preliminary Damage Assessment, Detailed Damage Assessment, and Extended Investigation. This document focused on the first two (FR and PDA). For the FR and PDA, element damage ratings and an overall marking classification were proposed. Roles for the different personnel involved with the response at each stage during emergency events were developed considering the expertise levels of the responders and to ensure efficient allocation of limited resources.

The proposed procedures and operational workflows can be utilized for rapid assessments during emergency situations and can be integrated with the National Bridge Inspection Standards database. These procedures were developed to be compatible with the National Incident Management System and a state's Incident Command Systems, and to facilitate communication and coordination with other federal and state agencies such as the Federal Emergency Management Agency and the Department of Homeland Security. When fully implemented, the process will improve coordination and communication within and between relevant agencies.

Preparing for emergency response can be overwhelming given the complexities and number of unknown variables. It is important that an agency starts the planning process and continues to improve it when allocating scarce resources prior to an event. With time and practice, personnel will become more comfortable and confident that they can respond when necessary. After the response is complete for an event, it is important to review and analyze the response efforts in order to update the emergency response plan accordingly.

While this assessing, coding, and marking system was developed based on today's state of the practice, supporting technologies for structural inspection evolve quickly with scientific and technological advances occurring at an increasing rate. All stages of the assessment process will benefit from the integration of appropriate technology. However, implementation of new technologies should consider institutional and technological maturity.

For FR, many advancing technologies, such as remote sensing, lidar, and structural health monitoring, may become much more useful in providing real-time, or near-real-time, emergency and damage information with computing and damage (health) analytics likely to mature in the near

future. Additionally, the use of single, small unmanned aerial and terrestrial vehicles or swarms of micro unmanned vehicles is expected to become widespread in the near future. Developments such as the integration of automatic positioning, vision-based navigation, and on-board photogrammetry will enable these vehicles to fill a significant gap between remote sensing-based and ground-based FR. In addition, crowdsourcing technologies have been proven effective toward providing real-time emergency information. It is expected that the widespread use and the promise of crowdsourcing as a result of augmented, mobile- and cloud-computing advances, and software design will play major roles in facilitating much faster and reliable reconnaissance.

In the case of PDA, mobile smart devices that integrate imaging, computing, GPS, communication, and smart apps are becoming ubiquitous today in normal and everyday use, enabling the notion of smart inspection, coding, and marking, which is expected to become the norm in the not-too-distant future. Significant advances may be on the horizon to integrate wearable smart devices (e.g., Google Glass), augmented reality (e.g., Microsoft HoloLens), computer vision, and artificial intelligence. This may make it feasible to realize semi-automatic assessment of highway structures based on collected imagery or used in pre-event training with mixed realities. Eventually, autonomous PDA may be ultimately realized as human-based PDA is replaced in the long term with breakthroughs in robotics, computer vision, and artificial intelligence technologies.

Finally, advanced GIS integration and interoperability technologies will become essential to support all assessment stages in the near future, given the trend toward big-data-enabled engineering in transportation asset management, remote sensing, autonomous vehicles, mobile computing, and crowdsourcing technologies that support disaster response (JST/NSF 2014).

MAP-21 mandates that each state develop a risk-based asset management plan for the National Highway System to improve or preserve the condition of the assets and the performance of the system. These include new requirements for more detail to collect element-level information on assets. Emergency response procedures should be an integral part of the asset management plans of each SHA.

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Acronyms and Abbreviations

APM	Assessment Process Manual
ATC	Applied Technology Council
CalOES	California Governor's Office of Emergency Services
Caltrans	California Department of Transportation
CPG	Comprehensive Preparedness Guide
DDA	Detailed Damage Assessment
DOT	Department of Transportation
EI	Extended Investigation
EMC	Emergency Management Coordinator
EOP	Emergency Operations Plan
EPP	Emergency Preparedness Plan
ERP	Emergency Response Plan
ESF	Emergency Support Function
FEMA	Federal Emergency Management Agency
FR	Fast Reconnaissance
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPR	Ground-Penetrating Radar
GPS	Global Positioning System
ICS	Incident Command System
IT	Information Technology
MBE	Manual for Bridge Evaluation
MSP	Michigan State Police
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NDE	Non-destructive Evaluation
NDT	Non-destructive Testing
NFPA	National Fire Protection Association
NIMS	National Incident Management System
NRF	National Response Framework
NYSDOT	New York State Department of Transportation
PDA	Preliminary Damage Assessment
PDAR	Preliminary Damage Assessment Responder
PennDOT	Pennsylvania Department of Transportation
QR	Quick Response
ROVER	Rapid Observation of Vulnerability and Estimation of Risk
SAP	Safety Assessment Program

SHA	State Highway Agency
SME	Subject Matter Expert
STIC	State Transportation Innovation Councils
UAV	Unmanned Aerial Vehicle
UAS	Unmanned Aerial System
WSDOT	Washington State Department of Transportation

Glossary

Term	Definition
Assessing	The process of evaluating a structure's condition through inspection and possible data analysis or modeling. This can be completed manually or through technological means.
Assessment forms	The assessment forms cover bridges, tunnels, walls, culverts, and overhead signs. These forms will be completed by Preliminary Damage Assessment responders in the field following an emergency event.
Basic Training	Training for all employees who will act as Preliminary Damage Assessment responders or perform Preliminary Damage Assessment after an emergency.
Chief (Structural, Geotechnical, Hydrological, Mechanical, Materials) Engineer	This role is reserved for the engineer who will coordinate specialty inspectors including structural, geotechnical, hydrological, mechanical, and materials.
Coding	The process of using a shortened notation or series of code to indicate the status of a structure, its components and elements, and other parameters associated with it.
Coding and Marking Guidelines	Volume 3 of this report, which will be used by Preliminary Damage Assessment responders for field assessments following an emergency event.
Communication	Communication focuses on the network.
Communication/Press Coordinator	This individual coordinates with the public and press from an informational point of view.
Coordination	Coordination primarily involves human resources.
Detailed Damage Assessment	Provides an evaluation of structural damage and decisions on use restriction after the Preliminary Damage Assessment.
Detailed Damage Assessment Inspector	These include structural inspection teams with significant background and experience for detailed inspection of structures.
Element Damage Rating	These damage levels (none, minor, moderate, or severe) are specific to basic structure elements and are used to provide information for repair, prioritization, and subsequent assessment procedures.

Emergency Data Coordinator	Individual who is responsible for coordinating all of the digital data, ensuring its quality, and providing that data in a form that is more useful for response.
Emergency Management Coordinator	Individual who will have responsibility for all coordination and communication in case of an emergency across the entire state highway agency.
Emergency Operations Plan	Emergency operations plans detail the scope of preparedness and emergency management activities that are required.
Extended Investigation	An in-depth inspection that requires specialized technologies. This stage is typically performed after an UNSAFE rating from the Detailed Damage Assessment stage.
Extended Investigation Inspector	These inspectors should be specialists (e.g., structural, geotechnical, hydrological, mechanical, materials) who will provide specific recommendations on necessary restrictions and/or repair, detailed damage analysis, and approximate cost estimate for remedial work.
Fast Reconnaissance	Provides a global perspective to establish the extent of the damage region immediately following an emergency event.
Fast Reconnaissance Coordinator	This individual is in charge of monitoring and organizing Fast Reconnaissance methods and reporting these findings in order to best determine the appropriate response levels.
General Training	Training for all personnel aiming to understand the assessing, coding, and marking processes.
Highway structure	Bridges, tunnels, walls, culverts, embankments, or overhead signs.
INSPECTED	This classification utilizes a green color and indicates that no apparent damage was found and the structure can function without further evaluation.
Inspection Routes	This is the list of highway structures that a Preliminary Damage Assessment responder will evaluate following an emergency event.
Inspector	Knowledgeable individual within an agency that has experience performing routine inspection of highway structures.
LIMITED USE	This classification utilizes a yellow color and indicates that minor to moderate damage conditions are observed or believed to be present. The structure requires further evaluation but can still be used for restricted traffic.
Logistics Coordinator	Responsible for coordinating logistics (travel, housing, hospitalization) support for the inspectors, particularly if staff is brought in from outside the state.
Managing Engineer	The managing engineer is the key lead for making all structural assessment decisions regarding highway structures.

Marking	The process of applying an identifiable mark to the structure to inform others of its condition. This can be done physically or digitally. The physical marking of a structure is sometimes referred to as "posting."
Minor damage	The element shows cosmetic or non-structural damage.
Moderate damage	The element has experienced structural or geotechnical damage.
Preliminary Damage Assessment	An assessment performed for each structure immediately after an event, preferably within hours, to provide information on the status of the structure and to determine whether subsequent assessment stages will be needed.
Preliminary Damage Assessment Responder	An individual who will perform Preliminary Damage Assessment evaluations following an emergency event.
Priority Level	Priority levels are given to highway routes that are of critical importance to the transportation network. These include lifeline routes and other routes that link important infrastructure.
QR Code	A machine-readable code consisting of an array of black and white squares, typically used for storing URLs or other information for reading by a camera or smartphone.
Response Levels	Responses levels relate to the immediacy of the response, the level of resources, and the effort that will be put into a response during an emergency event.
Severe Damage	The element is damaged where it cannot function properly.
Specialized Training	Training for emergency management coordinators, emergency data coordinators, chief engineers, Detailed Damage Assessment inspectors, and Extended Investigation inspectors.
Subject Matter Expert	Chief (structural, geotechnical, hydrological, mechanical, materials) engineers who report to the managing engineer.
UNSAFE	This classification utilizes a red color and indicates the structure has experienced severe damage or collapsed and cannot function properly under traffic loads.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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