NCHRP
RESEARCH REPORT 833

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

Volume 2: Assessment Process Manual

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

Volume 2: Assessment Process Manual

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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).

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FOREWORD

By Amir N. Hanna
Staff Officer
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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 *Research Overview,* which provides background information and an overview of the process, supporting manuals, and training materials, and *Coding and Marking Guidelines* are published as Volumes 1 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.

CONTENTS

SUMMARY

Assessing, Coding, and Marking of Highway Structures in Emergency Situations: Assessment Process Manual

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, tornados, 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 recent 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 ranges of traffic levels (i.e., the amount of traffic that a highway structure normally carries), or the methods employed by other responding agencies. To this end, the primary purpose of this manual 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 Purpose and Scope

The purpose of this manual is to provide a rapid, effective process for the assessing, coding, and marking of highway structures in emergency situations that can be implemented by state highway agencies (SHAs) across the United States. Although this process was developed with the intent of being adopted nationwide, this manual focuses on procedures that are intended to be implemented at the state and/or local transportation agency level.

This process includes pre-event planning, training, appropriate technology usage, prioritization strategies, coding and marking, coordination, communication, inspection procedures, and redundancy. A multi-tiered, priority-based approach that accommodates personnel with varying levels of expertise and experience is also included. The approach also incorporates scalable response levels such that the response effort efficiently matches the size of the event. The intent of this report is to provide the tools (process) necessary to effectively and uniformly assess, code, and mark the structures. It is *not* intended to provide suggestions as to the timing of repairs and the repair strategies in case of damage, nor does it cover highly detailed damage assessments.

This manual is not intended to supplant or replace the National Bridge Inspection Standards (NBIS) and its requirements for various inspections such as routine and fracture-critical member inspections. Rather, its intent is to develop procedures that can be utilized for rapid assessments during emergency situations in concert with the NBIS.

The following highway structure types are being addressed in this manual:

- Bridges
- Tunnels
- Walls
- Culverts
- Embankments
- Overhead signs

Special structures that may support a highway such as concrete dams are beyond the scope of this manual because they warrant more detailed analyses and additional procedures. Should the need arise, the proposed assessment, coding, and marking procedures can be adapted for other structures.

The following naturally occurring geological and meteorological events are included:

- Earthquake
- Tsunami
- Tornados
- Hurricane and storm surge

- High wind
- Flooding
- Scour
- Fire

Smaller, more localized events or events that typically do not result in damage to structures are not considered because they can typically be covered with established SHA protocols that do not require the level of detail presented in this manual. Examples include collision-related traffic accidents, explosions, landslides, mudflows, winter storms, ice storms, blizzards, sinkholes, or most man-made hazards. Volcanoes are also not directly addressed in this manual. However, because the manual is designed to generalize the process for a variety of emergency events, the process and procedures could be adapted for these hazards, should the need arise.

1.2 Audience

The primary audience for this 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, SHA chief structural engineers, chief geotechnical engineers, chief hydrological engineers, chief mechanical engineers, chief materials engineers, and their supporting staffs. Additionally, this manual is of use within the planning and preparation phases, which could be led by SHA's emergency response coordinators and heads of maintenance and safety.

In addition, sections of this manual are relevant to first responders such as inspectors, maintenance and operations personnel, design engineers, consultants, and others who will be involved in the emergency response and inspection of structures during and after emergency events. These persons should be familiar with the overall process and their critical roles. They should be capable of conducting a Preliminary Damage Assessment (PDA) and understand the details of that assessment stage as presented in this manual. Further, they should be able to implement the procedures described in *Volume 3: Coding and Marking Guidelines,* which was developed specifically for use in the field. While this manual is written for a target audience of transportation professionals, it is important that representatives from organizations who interface with SHAs are familiar with this manual so they can be informed regarding the safety of highway structures during emergency situations.

1.3 Background

Several SHAs 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 a uniform means for conducting these assessments or a common form of coding and marking on a nationwide basis. Also, these processes do not generally address the different highway structure types or the ranges of traffic levels. In addition, many of these processes do not explicitly consider the practices of other organizations that often respond to such emergencies. These issues can impede the effectiveness of involved organizations in dealing with these situations and may lead to undesirable consequences.

A nationally accepted, uniform process for the assessing, coding, and marking of highway structures in emergency situations is not currently available. This process manual was developed with the intent that it can fill that gap by being adopted by highway agencies and all other organizations that respond to such emergencies. Those transportation agencies who have emergency preparedness planning protocols in place may consider reviewing and adjusting those protocols where feasible to align themselves with the procedures recommended in this manual.

The procedures presented in this manual were developed based on the principal findings of a thorough background investigation consisting of both a literature review to establish the state of the art and an online questionnaire to establish the state of the practice.

The literature review analyzed common emergency events (described previously), critical highway structures, inspection technologies, emergency management and response, assessment procedures, and coding and marking practices. While the focus was on practices related to highway structures, the review also considered established practices for non-highway structures such as buildings.

An online questionnaire was distributed from February 24, 2014, to April 3, 2014, to the current membership of the AASHTO Subcommittee on Bridges and Structures, the Subcommittee on Maintenance, and the Special Committee on Transportation Security and Emergency Management. This questionnaire revealed information on current SHA procedural manuals and practices that are difficult to find via conventional means. These findings were incorporated into the processes described in this manual. The questionnaire was organized into sections including basic agency information, emergency preparedness and response, assessment procedures, coding and marking practices, training, technology and data usage, agency coordination, and guidelines.

1.4 Reference Material/Manuals

1.4.1 Associated Documents and Materials

Volumes 1 and 3 of this report are bound separately:

- *Volume 1: Research Overview*—This volume contains the background information that was used to develop this manual. The report contains more detailed information regarding current practices by various SHAs.
- *Volume 3: Coding and Marking Guidelines*—These guidelines were developed in concert with this manual. The guidelines were developed as a field manual in a flipchart format so that PDA responders (PDARs) can easily use it in the field.

Additionally, the following associated products are available:

- *NCHRP Web-Only Document 223: Guidelines for Developing Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations*—This document provides technical details and templates for creating a smart app for the PDA process.
- 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 one-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.
- Preliminary Damage Assessment Forms—Microsoft Word™ files as well as full-size pages containing the assessment forms for each structure type.

1.4.2 Existing Procedures

The process in this manual was developed based on several currently available procedures determined through the literature review and questionnaire. The primary references used as a foundation for this manual are as follows:

- Applied Technology Council (ATC)-20 Series
  - 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); and
  - ATC-20-2 *Addendum to the ATC-20 Post-earthquake Building Safety Evaluation Procedures* (ATC 1995).
- National Bridge Inspection Standards (FHWA 2004).
- *Manual for Bridge Evaluation* (MBE) (AASHTO 2011b).

In addition, several SHAs have developed hazard-specific guidelines and procedures manuals. The procedures tend to define from two to four response levels that are triggered by the magnitude of the emergency situation. They describe a two- to four-step evaluation flowchart (e.g., rapid, detailed, engineering as described in ATC-20). The guidelines often include inspection procedures, forms, typical damage photos, training information, and common repair and retrofit options. Table 1-1 summarizes the SHA information collected during this research. The information that was synthesized served as the basis for the assessment process presented in this manual.

Some key examples of processes that provided foundational material to this project include:

- New York State Department of Transportation (NYSDOT)—*Post-earthquake Bridge Inspection Guidelines* (O'Connor 2010)
- Utah DOT—*Bridge Management Manual,* Chapter 5: Emergency Response Plan (Utah DOT 2014a)
- Oregon DOT—*Seismic Lifelines Evaluation, Vulnerability Synthesis, and Identification* (CH2M Hill 2012)
- Oregon DOT—*ODOT Emergency Operations Plan,* Annex D: Bridge Damage Assessment (Oregon DOT 2014)
- California Governor's Office of Emergency Services (CalOES)—*Safety Assessment Program Evaluator Student Manual* (CalOES 2013)
- Pennsylvania DOT (PennDOT)—*Bridge Safety Inspection Manual* (PennDOT 2010)
- Indiana DOT—*Handbook for the Post-earthquake Safety Evaluation of Bridges and Roads* (Ramirez et al. 2000b) and *Field Guide for the Post-earthquake Safety Evaluation of Bridges and Roads* (Ramirez et al. 2000a)
- Kentucky Transportation Cabinet—*Post-earthquake Investigation Field Manual for the State of Kentucky* (Sardo et al. 2006)
- Washington State DOT (WSDOT)—*An Emergency Response Plan for Bridge Management* (Reed and Wang 1993).

This manual borrows from and builds upon these practices so that a consistent best practices approach is developed.

1.5 Definitions of Key Terms

To help with the readability of the manual, key terminologies, methods, and procedures are defined in this section. Note that each of these terms will be described in further detail later in this manual. A list of acronyms and abbreviations is provided later in this manual.

Table 1-1. Assessment, coding, and marking procedures currently in place by SHAs.

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/DoingBusiness/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] 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] 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

1.5.1 Assessing, Coding, and Marking

- 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.
- 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.
- 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."

1.5.2 Assessment Stages

The main types of inspections that will be conducted consist of stages ranging from quick overview assessments to slower, more detailed assessments:

- Fast Reconnaissance (FR)—Provides an overview to establish the extent of the damage region immediately following an emergency event.
- Preliminary Damage Assessment (PDA)—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. This stage is typically conducted by PDARs.
- Detailed Damage Assessment (DDA)—Provides an evaluation of structural damage and decisions on use restriction after the PDA. This stage is typically conducted by specialists (e.g., structural, geotechnical, hydrological, mechanical, and materials engineers).
- Extended Investigation (EI)—An in-depth inspection that requires specialized technologies. This stage is typically performed after an UNSAFE rating from the DDA stage.

Refer to Section 5.1 for more detailed definitions of these stages.

1.5.3 Response Levels

Response levels are indicators to help identify and communicate the level of resources needed based on the intensity of the event and number of structures affected:

Level I	Regular inspectors in the affected region(s) are placed on call to perform PDA.
Level II	SHAs can complete PDAs with their maintenance crews and DDAs using inspection crews.
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.
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 regions to assist with the PDAs.

Refer to Section 5.2 for more detailed definitions.

1.5.4 Element Damage Ratings

One of the following ratings is given to each element by a PDAR based on the amount of damage visually observed:

- None—The element shows no sign of damage.
- Minor—The element shows cosmetic or non-structural damage.
- Moderate—The element has experienced structural or geotechnical damage.
- Severe—The element is damaged where it cannot function properly.

Refer to Section 6.2 for more detailed definitions.

1.5.5 Marking Classifications

A final marking classification shall be assigned to each structure determining appropriate usage following an emergency event. The terms INSPECTED, LIMITED USE, and UNSAFE were chosen to be consistent with the process used for buildings (i.e., ATC-20):

- INSPECTED—This classification utilizes a green color and indicates that no apparent damage was found and the structure should be able to function without further evaluation.
- 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.
- UNSAFE—This classification utilizes a red color and indicates the structure has experienced severe damage or collapsed and cannot function properly under traffic loads.

Refer to Section 6.1 for more detailed definitions.

1.5.6 Emergency Management Roles

- Emergency management coordinator (EMC)—The EMC will have responsibility for overall coordination and communication in case of an emergency across the entire SHA. The EMC oversees the SHA's Incident Command Center and coordination with external agencies.
- Managing engineer—The managing engineer is the key lead for making all structural assessment decisions regarding highway structures. The managing engineer may assist the EMC when needed.
- 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.
- PDA responder—A PDAR is an individual who will perform PDA evaluations following an emergency event. For a Level I response, PDARs will typically be regular inspectors. For larger response levels, PDARs can be trained emergency responders (e.g., maintenance and operations crews, and design engineers).
- DDA inspector—These inspectors include structural inspection teams with significant background and experience for detailed inspection of structures.
- EI 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.
- Inspector—Inspectors are identified as knowledgeable individuals within an agency that have experience performing routine inspection of highway structures.

1.5.7 Operational Classification

Modified versions of AASHTO classifications for prioritizing bridges for earthquakes have been adopted for structural assessment prioritization in this manual (AASHTO 2011a):

- Critical—A structure that must remain open to all traffic after an emergency event and be usable by emergency vehicles and for security defense purposes immediately after a large event (e.g., 2,500-year return period). Critical structures are reserved for the most important structures in a transportation network. These structures are often the only means of connection on lifeline routes and are of the utmost importance to remain in service following an emergency event. These structures should be immediately evaluated using DDA by several teams of inspectors to examine the entire structure rather than proceeding with a PDA.
- Essential—A structure that should, at minimum, be open to emergency vehicles and for security purposes immediately after a design earthquake (e.g., 1,000-year return period event).

Essential structures are those that serve as integral links to lifeline routes. These structures should be evaluated for PDA before all other structures.

- Other—These structures include all other structures that are not classified as critical or essential.

Note that these definitions have been generalized for all hazards and structures and expanded to provide more examples in context of emergency response.

1.5.8 Assessment Criteria and Ranges of Traffic Levels

- Average daily traffic (ADT): the total traffic volume during a given time period, ranging from 2 to 364 consecutive days, divided by the number of days in that time period, and expressed in vehicles per day.
- Annual average daily traffic (AADT): traffic on a roadway link for all days of the week during a period of one year, expressed in vehicles per day.

1.6 Organization of the Manual

This manual is organized into the following chapters:

- Chapter 2 provides an overview of emergency events as well as common metrics used as intensity measures during emergency events. In addition, vulnerable structures are identified.
- Chapter 3 presents an overview of the general response process described in this manual.
- Chapter 4 describes important steps for planning and preparation to improve emergency response.
- Chapter 5 details the assessment stages including FR, PDA, DDA, and EI. This chapter also discusses response levels for the emergency events discussed in Chapter 2.
- Chapter 6 provides an overview of *Volume 3: Coding and Marking Guidelines.*
- Chapter 7 presents guidance on communication and coordination practices. This chapter also describes interfacing with relevant agencies and tools that can be used for communication during emergency situations.
- Chapter 8 highlights appropriate technologies for each of the assessment stages and how technology can aid in the assessment process. It also discusses considerations based on organizational and technological maturity levels.
- Chapter 9 provides the conclusions as well as an outlook on future technologies and practices that can be integrated into this process in the future.

Following the main text, the following additional materials are provided:

- Appendices
  - Appendix A: Highway Structure Background
  - Appendix B: Emergency Event Response Levels and Notifications
  - Appendix C: Traffic Levels and Capacity
  - Appendix D: Equipment List
  - Appendix E: Example Communication Flowcharts (from Utah DOT)
  - Appendix F: Assessment Forms
- A list of supporting references
- A list of acronyms and abbreviations
- A detailed glossary of terminology

CHAPTER 2

Emergency Events

2.1 Introduction

This section provides an overview of emergency events that can result in significant damage to highway structures in the United States. The emergency events include earthquake, tsunami, tornado, high winds, hurricane and storm surge, flooding, scour, and fire. The highway structures include bridges, tunnels, walls, culverts, embankments, and overhead signs. The type and magnitude of emergency events that highway structures face can vary significantly by location (e.g., geo-hazards) and are affected by seasons (e.g., meteorological hazards). In addition, although joint occurrence of different emergency events is not typically considered in design guidelines and codes (e.g., multi-hazard design), consequences of multiple events in sequence do occur in reality.

Whenever appropriate, causal relations between different emergency events are established in an effort to identify cascading events (e.g., earthquake-triggered tsunami or landslides, hurricane-triggered storm surge, and flooding-induced scour). Emergency event metrics will also be discussed to provide insight on the magnitude and extent of damage to highway structures. These metrics will be useful to provide a scale for assessing highway structures.

The various highway structures will respond very differently depending on the emergency event. Some structures are likely to be susceptible to hydraulic events while others to wind or earthquakes. Table 2-1 is a two-dimensional matrix highlighting the anticipated level of damage to highway structures corresponding to each emergency event based on the findings of the literature review. (Supporting material for the creation of this damage matrix can be found in Section 3.1 of Volume 1.) This table was developed based on the assumption that a significant emergency event has occurred, thus producing noticeable to significant consequences to a structure. 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 scale could jump one or two scale levels). Hence, this information is provided in a generalized context to aid in prioritizing response planning based on the likelihood or severity of damage to a given structure.

It is important to note that in some cases, highway structures are being used well past their design life or may have been rated as deficient due to wear from additional usage than was originally intended. Given the limited resources available for maintenance and upgrade in many SHA budgets, this can further complicate damage inspection, emergency inspection, and emergency event planning programs. This information should be considered when developing and assigning priorities for inspections. Consideration should also be given to structures that are vulnerable to specific emergency event types.

Table 2-1. Damage matrix in terms of emergency event types and highway structures.

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

Damage Scale

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

2.2 Warning Systems

In this section, warning systems for several emergency events will briefly be discussed. Warning systems vary significantly in their degree of accuracy and delay before response due to the unpredictable nature of emergency events. Notification systems such as Wireless Emergency Alerts provide emergency messages sent by authorized government entities alerting authorities through a mobile device [National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) 2014a]. The Wireless Emergency Alerts will send messages for tsunami, tornado, high wind, hurricane, and flood warnings. The NWS Storm Prediction Center provides interactive U.S. maps for tornado, high wind, hurricane, and flood warnings (NOAA/NWS 2014b).

Table 2-2 summarizes several warning notification systems that emergency management personnel can subscribe to. These warning systems will supply emergency event information to the subscriber's email address. This information helps emergency management personnel keep up to date with the most accurate and immediate notifications involving emergency events.

Table 2-2. Warning systems and URLs to their sites.

Warning System	Emergency Event(s)	Website URL
Earthquake Notification Services	Earthquake	sslearthquake.usgs.gov/ens/
Pacific Tsunami Warning Center	Tsunami	ptwc.weather.gov/ptwc/subscribe.php
Interactive NWS	Many	inws.wrh.noaa.gov/
Weather Alert Services	Many	www.weather.gov/subscribe
National Weather Service	Hurricane	www.weather.gov/subscribe-hurricaneinfo
GovDelivery	Many	www.govdelivery.com/

2.3 Earthquakes

An earthquake is defined as a violent and sudden shaking of the ground as a result of movements within the earth's crust or volcanic action. Earthquake seismic waves create multi-directional ground motions, which create displacements/deformations and forces/stresses within highway structures. In addition, supporting geotechnical elements (e.g., bridge foundation, retaining wall backfill, and embankments) are also subjected to distress and can fail. Earthquakes can also generate high pore water pressures and result in significant ground deformation through subsidence, landslides, liquefaction, or lateral spreading. Earthquakes can also trigger cascading hazards, which can cause physical damage to highway structures that may be weakened from the ground shaking. Examples of cascading hazards are tsunamis, aftershocks, fires, liquefaction, landslides, and lateral spreading.

The intensity of an earthquake is typically measured on one of two scales: the moment magnitude (M_W) scale or the modified Mercalli scale [U.S. Geological Survey (USGS) 2012, 2013]. For a detailed description of these terms, refer to Appendix B.

For engineering purposes, ground motion intensity measures are typically used to determine the intensity of shaking. These include peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration. Table 2-3 highlights the relationship between the perceived ground shaking, potential damage, PGA, PGV, and instrumental intensity.

The geographic extent and radius of damage is particularly difficult to predict for earthquakes due to the widely varying nature of their intensity. Earthquake intensity at a given site varies by distance from the epicenter and local site conditions. For example, Figure 2-1 highlights the PGA (in %*g*) of two M3.9 earthquakes that occurred in the United States. This figure reveals the variable nature of earthquake damage as this depends on geographical location and the inherent properties of the seismicity as well as source-to-site paths and soil classes.

Several highway structures are vulnerable during earthquakes. Table 2-4 provides examples of these vulnerable structure types.

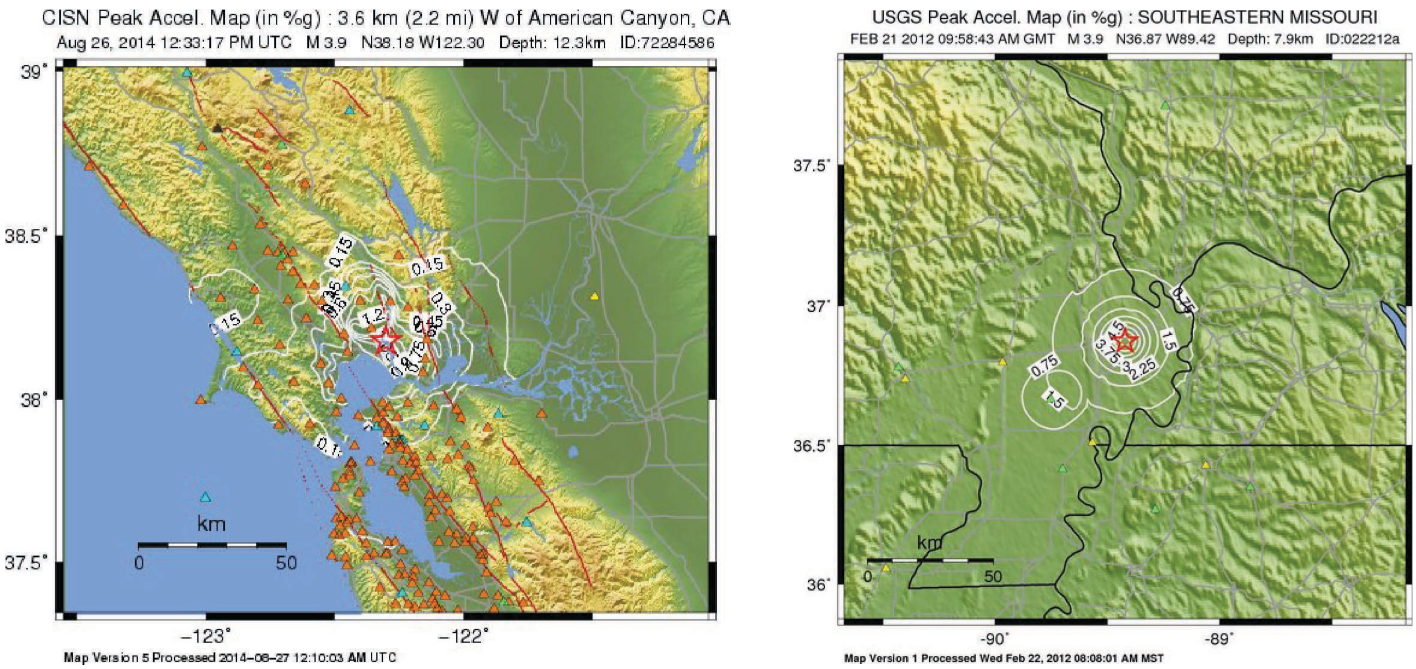
2.4 Tsunami

Coastal structures such as bridges, tunnels, walls (e.g., quay walls), embankments, culverts, and overhead signs can all face potential damage due to tsunamis. The destructive force of a tsunami is measured by both the initial impact of a large wall of water hitting a coastline at great velocities and the overwhelming amount of water flowing off the land producing large inundation heights and large water flow velocities. The tsunami inundation may also be slow rising with small to large flow velocities. In either form, forces acting on structures created by tsunami waves are in the form of hydrostatic, hydrodynamic pressures; impulsive forces; buoyancy; uplift; and debris-induced impact. Effects such as tsunami-induced liquefaction and foundation scour are also important to consider (Ghobarah et al. 2006, Rojahn et al. 2009).

Table 2-3. Intensity descriptions with the corresponding PGA and PGV values.

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	None	None	None	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very heavy
PEAK ACC (%g)	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Source: Modified from USGS (2014a).



Source: USGS (2014d).

Figure 2-1. USGS ShakeMaps showing PGA (in %g) for M3.9 earthquake in southern California **(left)** ***and M3.9 earthquake in southeastern Missouri*** **(right)*.***

Table 2-4. Highway structure vulnerabilities to earthquakes.

Structure	Vulnerability to Earthquake
Bridges	• Vulnerable bridge types susceptible to earthquake damage include the following (Arkansas DOT 2008): – Simple span structure or units supported on non-seismic bearings, and narrow bearing seats. – Continuous span structures with joints over piers, hinges, and/or pin and link systems. – Multi-span, non-continuous steel or concrete including multi-span PPC I-beams, and slab span bridges. – Structures with unusual geometry including skews greater than 25 degrees, severe or tight curvature, tall piers, piers or columns of different heights, stair-stepped bearing seats for superelevation, unusually long continuous spans, piers in deep water, and two girder systems.
Tunnels	• The major factors associated with increased mountain tunnel damage include the tunnel being located adjacent to surface slopes or portals, the tunnel running through faults, the absence of concrete lining, unusual or unfavorable concrete lining conditions, steep sidewalls, or absence of an invert (Wang et al. 2001).
Walls	• Seismic performance of retaining walls is typically good with little to no problems or damages (Verdugo et al. 2012). However, other types of walls can be more vulnerable since they do not have confinement pressure and friction from the soil behind the wall. • Lateral movements, tilting, and settlements of walls (Argyroudis et al. 2013).
Culverts	• Culverts become vulnerable in areas affected by foundation failure or subject to large lateral or inertial forces (Youd and Beckman 1996). • Liquefaction-induced embankment penetration, slope instability, and fault rupture (Youd and Beckman 1996).
Embankments	• Embankments are susceptible to liquefaction and sliding failures (Adalier et al. 1998, Koseki et al. 2012).

Table 2-5. Highway structure vulnerabilities to tsunamis.

Structure	Vulnerability to Tsunami
Bridges	• If there is no shear key, the bridge becomes more susceptible to being significantly displaced or washed out (Unjoh 2006). • Uplift and subsequent unseating and washout was observed in many bridges in the 2011 tsunami in Japan due to insufficient resistance of bearings to uplift. • Failure of bridge abutments, supporting piers, and foundations (Azadbakht 2013).
Tunnels	• Tunnels in low-elevation locations near an ocean are susceptible to flooding.
Embankments	• Soil embankments with soft materials are more susceptible to being washed away (Yashinsky 2011).

Highway structures are particularly vulnerable to the initial wave; the runup and drawdown flows; and the associated hydraulic/hydrodynamic, debris, and scour impacts. The complex impact and damage for transportation structures can be found in the field reports (EERI 2011, Francis and Yeh 2006).

The parameter that is the most useful measure to correlate and identify possible tsunami damage is inundation height, which can be transformed to maximum runup distances.

Highway structures that are particularly vulnerable to tsunami impact are highlighted in Table 2-5.

2.5 Tornado

Tornados are one of the most damaging forms of severe weather within the United States (Changnon 2009). Tornado intensity is rated using the enhanced Fujita (EF) scale (NOAA/NWS 2014c), where the intensity of the tornado ranges from EF-0 to EF-5 based on the damage to structures and vegetation on the tornado path (Table 2-6). The official EF rating is often determined after ground-based or aerial damage surveys, which can take up to a couple of days after the tornado. However, preliminary estimates about the EF rating of a tornado and the size of affected areas can be made right after a tornado, which can help managing engineers to estimate the required level of response. Table 2-6 presents wind speeds and typical damage states related to each EF level.

Table 2-6. EF scale with example damage.

Wind Speed (mph)	EF Scale	Example Damage
65–85	EF-0	Light damage. Peels surface off some roofs; some damage to gutters or siding; branches broken off trees; shallow-rooted trees pushed over.
86–110	EF-1	Moderate damage. Roofs severely stripped; mobile homes overturned or badly damaged; loss of exterior doors; windows and other glass broken.
111–135	EF-2	Considerable damage. Roofs torn off well-constructed houses; foundations of frame homes shifted; mobile homes completely destroyed; large trees snapped or uprooted; light-object missiles generated; cars lifted off ground.
136–165	EF-3	Severe damage. Entire stories of well-constructed houses destroyed; severe damage to large buildings such as shopping malls; trains overturned; trees debarked; heavy cars lifted off the ground and thrown; structures with weak foundations blown away some distance.
166–200	EF-4	Devastating damage. Well-constructed houses and whole frame houses completely leveled; cars thrown and small missiles generated.
>200	EF-5	Incredible damage. Strong frame houses leveled off foundations and swept away; automobile-sized missiles fly through the air a distance in excess of 100 m; high-rise buildings have significant structural deformation; incredible phenomena will occur.

Table 2-7. Highway structure vulnerabilities to tornados.

Structure	Vulnerability to Tornado
Overhead Signs	• Overhead signs may experience foundation failures or fatigue damage. • Impact from debris. • Partial or complete collapse.

Besides the wind gust loading on transportation structures, one of the most damaging aspects of tornados in regards to highway structures is impact from wind-borne debris. Tornado wind speeds can exceed 300 mph and can lift houses, motor vehicles, and trees moving them over 100 yards. Tornados often create and transport large amounts of debris that can be ejected at high velocities (Pierce et al. 2009).

Most highway structures are relatively safe against tornado impact. Those that are most vulnerable are discussed in Table 2-7. Debris impacts, however, are important to consider.

2.6 Hurricane and Storm Surge

Hurricane intensity is measured by the Saffir–Simpson hurricane scale (NOAA/NWS 2013), and can receive a category rating of 1 to 5 (Table 2-8).

Associated with extreme winds, heavy rainfall, flooding, and storm surge, landfalling hurricanes often cause great destruction to coastal regions (Ning 2010). The extent of damage from hurricanes is not entirely dependent on the strength of the storm, but also the way it makes contact with the coastline. This combination of hazards can cause significant damage to highway structures within the range of a storm.

Storm surge is a complex phenomenon produced by water being pushed toward the shore from wind forces generated by a storm such as a hurricane. Hurricanes cause widespread damage

Table 2-8. Saffir–Simpson hurricane wind scale.

Hurricane Category	Wind Speed (mph)	Storm Surge (ft)	Damage	
1	74–95	4–5	Minimal	Usually no significant structural damage to building structures. Unanchored mobile homes can be toppled. Trees can be uprooted or snapped. Poorly attached roof shingles or tiles can blow off.
2	96–110	6–8	Moderate	Greatly strong. Can lift a house. Can inflict damage upon poorly constructed doors and windows. Vegetation receives considerable damage. Mobile homes damaged. Manufactured homes suffer structural damage.
3	111–130	9–12	Extensive	Can cause structural damage to small residences and utility buildings. Buildings without solid foundations usually destroyed. Manufactured homes sustain severe damage. Flooding of terrain near coast destroys structures.
4	131–155	13–18	Extreme	Extensive damage to roofing materials and non-loading walls. Complete structural failure of roofs on small homes. Major damage to lower floors of structures near the coast. Major erosion of beaches. Evacuation of low ground up to 6 mi from the coast.
5	>156	≥ 19	Catastrophic	Complete roof structure damage on many buildings. Some complete building failures. Small utility buildings blown over. Major damage to lower floors near the coast. Evacuation of low ground up to 10 mi from the coast.

Source: NOAA/NWS (2013).

Table 2-9. Highway structure vulnerabilities to hurricane and storm surge.

Structure	Vulnerability to Hurricane and Storm Surge
Bridges	• If low-elevation bridge spans are more susceptible to unseating of individual spans (Padgett et al. 2008). • Low-level coastal bridges can become partially or completely submerged creating hydrodynamic uplift forces (Azadbakht 2013, Robertson et al. 2007). • Moveable bridges are vulnerable during hurricanes. Increased exposure to salt water may permanently damage motors and wiring (O'Connor and McAnany 2008). • Deck unseating (Ataei et al. 2010).
Tunnels	• Salt damages electrical components. • Debris may clog the opening leading to widespread flooding.
Culverts	• Significant loss of fill around the culvert. • Storm surge inundation. • Debris may clog the opening leading to widespread flooding.
Embankments	• Overtopping leading to failures.

to coastal regions, but tropical, cyclone-generated storm surges are among the most costly and deadly natural emergency events to affect the United States (Needham and Keim 2012). The size of the storm surge depends on storm intensity, size, forward speed, central pressure, approach direction toward the coast, the properties of the coastal features, and width and slope of the continental shelf.

Highway structure vulnerabilities to hurricane and storm surge are highlighted in Table 2-9.

2.7 High Winds

The Beaufort scale categorizes wind speeds and their conditions on land (NOAA/NWS 2014d). Wind events can receive a number rating (force) of 0 to 12 (Table 2-10).

Winds in excess of 58 mph can create damage that is tornado-like in nature. This is especially true in the case of a downburst, which is a strong downdraft resulting in an outward burst of damaging winds at or near the ground (National Science and Technology Council 2006).

High wind impacts on highway structures are significantly less than that of hurricanes or tornados; however, there is still the potential of impact damage from debris. It is now a

Table 2-10. Beaufort scale.

Force	Wind Speed (mph)	Name	Conditions on Land
0	<1	Calm	Smoke rises vertically.
1	1–4	Light air	Smoke drifts and leaves rustle.
2	5–7	Light breeze	Wind felt on face.
3	8–11	Gentle breeze	Flags extended, leaves move.
4	12–18	Moderate breeze	Dust and small branches move.
5	19–24	Fresh breeze	Small trees begin to sway.
6	25–31	Strong breeze	Large branches move, wires whistle, umbrellas are difficult to control.
7	32–38	Near gale	Whole trees in motion, inconvenience in walking.
8	39–46	Gale	Difficult to walk against wind. Twigs and small branches blown off trees.
9	47–54	Strong gale	Minor structural damage may occur (shingles blown off roofs).
10	55–63	Storm	Trees uprooted, structural damage likely.
11	64–73	Violent storm	Widespread damage to structures.
12	74+	Hurricane	Severe structural damage to buildings, widespread devastation.

Source: NOAA/NWS (2014d).

Table 2-11. Highway structure vulnerabilities to high winds.

Structure	Vulnerability to High Winds
Overhead Signs	• Overhead signs are susceptible to fatigue damage due to wind loading. • Breakage or blow-off caused by high wind pressures and wind-borne debris impact.
Bridges	• Winds can cause vibrations and torsion in bridges. However, these are typically isolated incidents.

well-established principle in the design of almost all above-ground structures to make allowance for wind pressures. This design criterion makes highway structures particularly safe against wind loading.

Highway structures that are particularly vulnerable are those that are higher in the air because wind speed increases with height above ground. In addition, structures with larger surface area perpendicular to the direction of wind will experience higher levels of loading. The most critical highway structures are those that are susceptible to impact debris from wind gusts. Bridge closures are based on wind speed and facility conditions. For example, Virginia DOT will close the Route 17 James River Bridge with the onset of 45 mph winds (Virginia DOT 2012).

Many highway structures are not vulnerable to high winds. The primary concern in high winds is the damage due to debris. Those structures that are vulnerable are detailed in Table 2-11.

2.8 Flooding

Floods can be coastal flooding, riverine flooding, or urban flooding. The NWS maintains a reasonably consistent, long-term record of flood damage throughout the United States. Although there is no official scale for assessing general flood hazards risks, for riverine flooding only, the flow intensity scale (Table 2-12) relates water-flow velocity to potential damage. This is based on the well-known fluid-flow intensity scales (Beaufort and Saffir–Simpson wind scales) that relate wind velocity to possible structural damage (Fulford 2004). For coastal flooding, storm surges are the leading form of damage and can be further triggered by a hurricane event. Thus, the Saffir–Simpson hurricane scale was recommended by the NOAA, which

Table 2-12. Flow intensity scale for riverine flooding.

Flow Scale	Wind Category	Water Velocity (ft/s)	Effect
1	B 7	1.6–2	Some erosion occurs. Wade-able.
2	B 8	2–2.4	Sandy soils erode some. Foundations may scour in sandy soils.
3	B 9	2.4–2.8	Unsafe for auto crossing. Sandy soils erode extensively. Wading can be difficult.
4	B 10	2.8–3.3	Rip current, as fast as a 50 m Olympic swimmer. Grass-type vegetation erodes.
5	B 11	3.3–3.8	Gravels move. Foundations may scour in most soils.
6	SS 1	3.8–4.9	Most bare soils scour. Grass-type vegetation is extensively eroded. Gravels, cobbles, and small rocks move. Building damage possible.
7	SS 2	4.9–5.6	Floodplain grass removed by flow. Some shrubs are bent over by the flow depending on flow depth.
8	SS 3	5.6–6.7	Begin to expect significant impact. Damage to structures.
9	SS 4	6.7–8	Shales and hardpan soils erode.
10	SS 5	>8	Extensive scour occurs. Large rocks are moved. Shrubs are removed. Major damage or destruction of most structures.

B = Beaufort scale; SS = Saffir–Simpson scale
Source: Fulford (2004).

Table 2-13. Highway structure vulnerabilities to flooding.

Structure	Vulnerability to Flooding
Bridges	• Hydrostatic and hydrodynamic forces. • Scour and/or erosion of abutments. • Impact and accumulation of floating debris on the decks, piers, and abutments.
Culverts	• Floodwaters can erode culvert entrances or outlets. • Areas of high velocity flow can experience overtopping.
Embankments	• Embankments can experience scour, slope instability failures, erosion, overtopping, and liquefaction.

incorporates storm surge as a component of each scale category. Storm Surge Interactive Risk Mapping being developed by the NOAA uses a simulation model (SLOSH) to generate a systematic flooding vulnerability map considering hurricane landfalls, local bathymetry, and topography (NOAA/NWS 2014e).

The vulnerabilities of highway structures during flood events are highlighted in Table 2-13.

2.9 Scour

Scour is defined as the erosion or removal of streambed or bank material due to flowing water. In general, scour can be induced by riverine flooding, tsunami waves, and storm surges. Therefore, scour is separated herein as a stand-alone hazard. Knowledge regarding scour due to tsunami runup and drawdown or storm surges remains insufficient, subject to extensive research to date. Reference standard documents for all scour evaluation programs, which are mainly for riverine flooding-induced scour, include the following:

- *Hydraulic Engineering Circular No. 18: Evaluating Scour at Bridges* (HEC-18) is the technical standard for knowledge and practice in the design, evaluation, and inspection of bridges for scour. There have been five editions of HEC-18 (Richardson et al. 1991, Richardson et al. 1993, Richardson and Davis 1995, Richardson and Davis 2001, Arneson et al. 2012).
- *Hydraulic Engineering Circular No. 20: Stream Stability at Highway Structures* (HEC-20) provides guidelines for identifying stream instability problems at stream crossings that may cause scour damage to bridges and culverts (Lagasse et al. 2012).
- *Hydraulic Engineering Circular No. 23: Bridge Scour and Stream Instability Countermeasures* (HEC-23) identifies and provides design guidelines for bridge scour and stream instability countermeasures (Lagasse et al. 2001).
- Technical Advisory T5140.23: Evaluating Scour at Bridges, dated October 28, 1991 (FHWA 1991a), provides more guidance on the development and implementation of procedures for evaluating bridge scour to meet the requirements of 23 Code of Federal Regulations 650, Subpart C. This advisory provides guidance on the following:
  – Developing a procedure for predicting scour potential of new bridges
  – Evaluating existing bridges for scour vulnerability
  – Using scour countermeasures
  – Improving the state of the practice for estimating scour at bridges
- FHWA Memorandum "Scourability of Rock Formations," dated July 19, 1991 (FHWA 1991b) provides guidance on the scourability of rock formations.

The National Bridge Inventory (NBI) denotes field 113 to identify the current status of a bridge regarding its vulnerability to scour (FHWA 2015a). See Table 2-14 for the descriptions of the codes used.

Table 2-14. Codes in NBI field 113.

Codes	Description
N	Bridge is not over waterway.
U	Unknown foundation that has not been evaluated for scour. Due to risk being undetermined, flag for monitoring during flooding events.
T	Bridge over "tidal" waters that has not been evaluated for scour but is considered low risk. "Unknown" foundations in tidal waters should be coded U.
9	Bridge foundations on dry land well above flood water elevations.
8	Bridge foundations determined to be stable for the assessed or calculated scour condition. Scour is determined to be above top of footing by assessment, calculation, or installation of properly designed countermeasures.
7	Countermeasures have been installed to mitigate an existing problem with scour and to reduce the risk of bridge failure during flood event.
6	Scour calculations/evaluation has not been made. (Use only to describe case where bridge has not yet been evaluated for scour potential.)
5	Bridge foundations determined to be stable for assessed or calculated scour condition. Scour is determined to be within the limits of footings or piles by assessment, calculations, or installation of properly designed countermeasures.
4	Bridge foundations determined to be stable for assessed or calculated scour conditions; field review indicates action is required to protect exposed foundations.
3	Bridge is scour critical; bridge foundations determined to be unstable for assessed or calculated scour conditions: scour within limits of footings or piles, or scour below spread-footing base or pile tips.
2	Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations, which are determined to be unstable by a comparison of calculated scour and observed scour during the bridge inspection or an engineering evaluation of the observed scour reported by the bridge inspector.
1	Bridge is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic. Failure is imminent based on a comparison of calculated and observed scour during the bridge inspection or an engineering evaluation of the observed scour condition reported by the bridge inspector.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.

Source: Modified from Richardson and Davis (2001).

2.10 Fire

Bridge fire is usually caused by vehicle crashes that result in gasoline burning or flammable chemical incidents in the vicinity of highway bridges. Gasoline fire is much more severe than regular building fire and is usually characterized by high heating rate and peak temperature. Therefore, gasoline fires on bridges, if not extinguished and controlled, can quickly damage structural members leading to bridge collapse (Garlock et al. 2012).

Wildfires are less likely to cause damage to highway structures because they often occur in the countryside or wilderness areas; however, there is still the risk of the fire spreading and causing damage to highway structures within its range. The extent of a wildfire is much greater than that of vehicle fires, which are typically local and only affect a few structures. Further, rainfall after wildfires can result in debris flows because of the loss of vegetation.

Common highway structure vulnerabilities with fire events are highlighted in Table 2-15.

Table 2-15. Highway structure vulnerabilities for fire.

Structure	Vulnerability to Fire
Bridges	• Cracking and spalling of concrete. • Melting of steel bridges. • Burning and fire of timber bridges resulting in reduced strength or collapse.
Tunnels	• Fires in tunnels can lead to cracking and spalling, overheating of the reinforcing steel, and collapse of false ceilings.

CHAPTER 3

Response Process Framework

This chapter presents the general framework for the response process. Details of the key phases within the scope of this manual will be presented in subsequent chapters. To place these phases in context, Table 3-1 provides an overview of the timeline for a general emergency response. In this approach, planning ("First You Plan") and proactive efforts are stressed and will be covered in more detail in Chapter 4.

To be deployable by a wide variety of organizations in emergency situations, this methodology was developed to be efficient, comprehensive, and inclusive. Implementation is not a trivial matter given the number of variables that must be considered, many of which are beyond the control of the emergency response planners. The methodology covers a diverse range of structure types, ranges of traffic levels, as well as the type of event in order to determine priorities, particularly for the critical period immediately after an event. The methodology also considers coordination among multiple organizations that may have an interest in assessing these structures so as to avoid overlap and maximize the effectiveness of the response effort.

The process is multi-tiered in order to accommodate and recognize the skill of the "inspector," the available technology and resources, the agencies involved in the response, the type of structure, the type of event, and the ranges of traffic levels. This applies to the coding and marking procedures as well.

Of the four assessment stages proposed (and described in detail in Section 5.1), this manual concentrates on the FR and PDA stages that need to be completed rapidly after an emergency event. Response levels are also defined to help determine the quantities of personnel required based on the size of the event.

The first stage, FR, is important to obtain an overview and determine the overall extent of damage. Results from FR help prioritize the on-site assessments in the PDA, DDA, and EI stages.

PDARs then need a simplified, rapid procedure for identifying basic damage states. The assessment process can minimize subjectivity from the inspection process through the use of fail-safe automation based on consistency of data collected in this systematic workflow. However, this procedure is different (and should never replace) the procedure used by a trained structural engineer or inspector who can afford to spend more time on each site during a routine inspection (e.g., NBIS), resulting in greater detail. Those inspections also can utilize more advanced technologies.

To help with the PDA process and reporting of results, *Volume 3: Coding and Marking Guidelines* was developed to assist the PDARs through a number of possible damage scenarios and

Table 3-1. 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.

emergency events. It also provides additional details and examples to help PDARs perform a rapid assessment. Suitable technologies are recommended for each type of inspection and at each stage in the response timeline.

Any emergency response plan must have built-in redundancy in terms of alternative inspection methods that take into account individual agencies' constraints. It must be recognized that telecommunications links, access to information, and access to the actual structures may or may not be available. Consequently, a two-part, fail-safe approach is recommended that can utilize smart devices via a smart app (see *NCHRP Web-Only Document 223: Guidelines for Developing Smart Apps for Assessing, Coding, and Marking Highway Structures in Emergency Situations*) when communication infrastructure is available and falls back on manual and paper-based forms as a last resort when digital devices cannot be used.

CHAPTER 4

Planning and Preparation

4.1 Overview

This manual is grounded with a "First You Plan" strategy to support an effective and coordinated assessment, coding, and marking process during emergency events. The goal of the planning and preparation phase is to anticipate and train for as many of the likely emergency scenarios as possible so that the needed response can be identified, planned, prepared for, and effectively coordinated with a minimum of crisis management. While specific guidance for all work necessary at this stage is not directly within the scope of this document, it is important to discuss relevant preparatory tasks and efforts that can provide the foundation for the emergency response procedure presented in this manual.

During the pre-event planning and preparation, regional factors, interagency needs, and communication issues can be identified and addressed in a non-emergency environment. Proper planning can ensure that limited resources for data collection (including installation, training, and maintenance of equipment for inspection) are available and optimally allocated.

Proper planning and relatively low-cost, pre-event mitigation, in most cases, will result in less costly emergency response and recovery in the long term. Insufficient preparation and neglect is obviously an unnecessary risk and can be more costly in the long run if an emergency response is conducted inefficiently. It can also lead to costly litigation.

A proactive approach of mitigation prior to the event can often be less costly than a reactive approach of repairs after an emergency event, particularly when economic consequences of disruption to the highway network are considered. These mitigation efforts also have benefits in day-to-day use beyond emergency preparation.

However, one should also note that allocating excessive resources to preparation at the expense of daily operations and safety needs can have worse consequences. Hence, each SHA should routinely assess its preparation state to determine whether it is adequate, insufficient, or excessive based on the frequency of emergency events, potential size of the events, and condition and number of structures likely to be affected.

Planning and preparation is an ongoing effort. Each organization should frequently evaluate the status of its emergency preparation planning so that it can develop and implement the necessary corrective actions. The magnitude of effort of these evaluations will depend on the relative amount of risk in a locale. For example, in some areas, large hazardous events may be infrequent but still pose significant risk. In such locales, it can sometimes be difficult to gather the necessary public support for allocating resources in these locations since the public may not perceive the risk. In such cases, public outreach and education efforts through partnerships with state emergency response and hazard agencies (e.g., geology department) and universities may help break down these barriers.

Table 4-1. Questions for planning stages and preparation phases.

Theme	Question
Development of Emergency Operations Plans	• How do structural assessments fit into the overall emergency operations plan? • How does the process coordinate with the broader missions of the agency?
Data Infrastructure and Asset Management	• What data and software tools need to be readily accessible to coordinate an emergency response? • What is the current status of that data and its quality? • How often does that data need to be updated? • How can this information be collected more efficiently during bridge inspections and asset management inventories?
Equipment and Resource Infrastructure	• What resources are needed and what are available? • What resources should be dedicated to the emergency response and which should be shared with regular operations? • What is our agency's maturity level with technology? Which technologies are appropriate and available for emergency response? How can we use these in our workflows? • How much should be invested in emergency response preparation from the annual budget? • How often are updates and upgrades needed?
Emergency Event Planning	• What emergency events are most likely to occur? • Which areas/structures are likely to be affected significantly because of the intensity of the event and the vulnerability/condition of the structure? • Which structures and highway routes are the most critical to assess to ensure a rapid recovery?
Traffic Levels	• Are highways, strategic routes, and primary distributors identified by attributes and functional classification? • Are traffic levels (i.e., annual average daily traffic data) collected?
What-if Analysis	• Have ShakeCast and ShakeMap scenarios been established? • Are other scenarios established for other emergency events? • Are relevant structure data provided to provide realistic scenarios?
Preparation for PDARs	• Are PDARs familiar with their routes? • What alternate routes are available in case highways are blocked? • What personnel are available to assist in emergency response?
Training	• What mechanisms are in place if staff needs to be borrowed? • What material should be presented in training? • How often should this training be conducted? • Who should be present?
Communication, Coordination, and Preparation	• Does the agency have established intra- and interagency communication strategies? • How often is agency contact information updated?
Important Emergency Management References	• Is the agency familiar with standards such as the Multiagency Coordination System, National Incident Management System, and National Infrastructure Protection Plan? • Is the emergency operations plan based on *Comprehensive Preparedness Guide 101*? • Is the agency familiar with Homeland Security Presidential Directive National Preparedness guidelines?

In the following sections, a number of resources will be identified that can aid in the planning and preparation for an emergency event. A number of key questions that should be asked during the planning stage are highlighted in Table 4-1.

4.2 Development of Emergency Operations Plans

Emergency operations plans (EOPs) detail the scope of preparedness and emergency management activities that are required. SHAs will either have a stand-alone EOP or the agency's plan will be an element of the state's overall EOP. All levels of government—local, tribal, state, and federal—including their division offices—prepare formal EOPs to establish authority, responsibilities, and procedures for how the organization will operate in response to a disaster or emergency event.

The federal government has provided many tools to state and local agencies for developing EOPs; most notable is the *Comprehensive Preparedness Guide* (CPG) *101*. The CPG 101 provides guidelines to help planners at all levels of government in their efforts to develop and maintain viable all-hazards, all-threats EOPs [Federal Emergency Management Agency (FEMA) 2010b]. FEMA recommends that teams responsible for developing EOPs use CPG 101 to guide their efforts.

Based on the questionnaire results, 80% of SHAs have an emergency response plan (ERP) or an emergency preparedness plan (EPP) on file that is either comprehensive for most emergency events (60% of SHAs) or different for each event (20% of SHAs). These plans are action and task oriented, enabling agencies to respond to serious incidents regardless of their cause. States in seismic and flood-prone areas likely have more comprehensive plans dealing specifically with the post-disaster assessment of structures.

States not frequently affected by natural emergency events are less likely to have comprehensive plans to deal with widespread damage. Nonetheless, EPPs are vital to prevention, protection, response, and recovery from emergencies of all kinds. These plans are consistent with the National Incident Management System (NIMS) and provide hazard-type annexes that outline details about threat-specific responsibilities.

It is important that the EOP seamlessly integrate the process of assessing, coding, and marking highway structures with the overall response operations of a transportation agency.

Key Recommendations for Developing Emergency Operations Plans

- Incorporate structural assessments into the current EOP.
- Establish the coordination process with the broader missions of the agency.

4.3 Data Infrastructure and Asset Management

This section will describe key components of data management that should be in place for effective response. These include, but are not limited to, geographic information system (GIS) infrastructure (software and hardware), structural inventory databases, road networks, and traffic information. *NCHRP Report 748: Guidelines for the Use of Mobile Lidar in Transportation Applications* provides guidelines for utilizing mobile lidar to acquire a variety of information to develop powerful GIS databases to support a wide range of transportation applications.

All of these data should be linked in a geospatial context so that they can be quickly coordinated with information from the emergency event in order to determine likely vulnerability. A detailed database will not be generated overnight. It will require long-term persistence and contributions from various departments throughout the organization. Routine updates, edits, and use of the database will enable it to be applied more effectively during emergency situations and for people to have more confidence in it. Paths of data sharing should be identified and thoroughly tested. The following subsections discuss examples of critical data infrastructure.

Access to the database information can be seamlessly provided through the use of quick-response (QR) codes that can be placed on structure identification placards. QR codes placed permanently on the structure ID placard can be used during routine inspections (e.g., NBIS) and also during emergency situations to readily access data for the structure. In addition, QR codes can be placed on documents that refer to the structure of interest (e.g., paper-based reports) for ease of access. QR codes enable rapid access to other documents and information, such as previous inspection reports, structural databases, and photographs. They can improve coordination between agencies during routine inspection as well as emergency situations. When a QR code is not placed on the structure prior to an emergency event, the field engineer can create and place a QR code on the inspection placard.

Asset management information and pavement management systems linked to structures are important elements in preparing for emergency response and decision making. One example of asset management data is Utah DOT's U-Plan website, which is an interactive, collaborative mapping platform that integrates data from various divisions within the DOT (Utah DOT 2014b). The intent of this system is to enable users to rapidly visualize data, track asset performance, and strengthen transportation planning. With this type of asset management system, planning and preparation procedures for emergency events can be better informed. Such an approach for the development of transportation asset management plans is a requirement of the recent MAP-21 legislation. States must address pavements and bridges on the National Highway System in their risk-based management plan. They are encouraged to include all infrastructure assets within the highway right-of-way in their risk management plan as well. It is also now required that each state and federal agency provide element-level bridge inspection data for bridges on the National Highway System.

4.3.1 Geographic Information Systems

GIS provides a framework to integrate multiple types of data through geospatial coordinates and linked attributes. Through development of organized and systematic databases, information can be rapidly queried, compared, and analyzed. As a result, the use of GIS has been widely popular for emergency response given its ability to provide critical information rapidly, while creating useful response maps based on spatial data and field analysis (Barich et al. 2013, FEMA 2013). While use of GIS for transportation activities has been popular, its usage for structural engineering has been somewhat limited (Olsen et al. 2013). Most state and/or federal agencies have produced various hazard maps to indicate the variability of expected damage across a state. These maps can be used for planning purposes to identify structures that are most vulnerable, create inspection routes, perform simulations, and determine anticipated needs. Examples of relevant geospatial data are listed in Table 4-2.

Similar to GIS, Civil Integrated Management (FHWA et al. 2012) expands the concept of GIS and Building Information Modeling to contain detailed, three-dimensional models of structures as well as their attributes (e.g., materials, dimensions, linked information from inspection reports). When such systems are in place prior to an event, it can provide PDARs and inspectors with important information on the structure's history and previous inspection results.

In emergency response, GIS can be used to quickly identify structures within a radius of an earthquake's epicenter or a distance from a tornado's path to narrow down these inspection lists and help establish priority. When ShakeMaps or similar products are available, the list can be further narrowed down by examining fragility-based damage estimation (e.g., through use of Hazus-MH). The prioritization can also be updated with incoming PDA reports; however, numerous updates should be avoided because they can confuse and delay inspection teams.

4.3.2 Structural Inventory Databases

Development of structure inventory and maintenance databases that tie structures to their geospatial location, traffic levels, condition, and other pertinent information can help determine their vulnerability during emergency events as well as their relative priority compared to other structures. To ensure rapid response and querying of the data, it is important to have an integrated database system.

A primary national-level database that has been used frequently by the practice and research communities for bridge data references is the NBI database (FHWA 2015a). The SHAs hold the

Table 4-2. Examples of relevant geospatial data (often available through online viewers, Google® Earth™, and GIS data layers).

Data Source	Description	Applicable Emergency Events
U.S. Geological Survey ShakeMap (USGS 2014d)	Based on accelerometer data following an earthquake, the USGS can immediately create a map showing the distribution of earthquake intensity (modified Mercalli intensity). When such data are integrated in a GIS with information regarding the location of structures, an agency can quickly identify which structures are most likely to be damaged. In some cases, predictive maps have been created to show areas where damage is likely.	Earthquake
FEMA Flood Maps (FEMA 2014)	FEMA flood maps provide detailed delineations of where water levels would be expected to reach during various probabilistic storm events. While the primary intent of these maps is for insurance loss estimation, they can be useful to plan and identify structures that would be most vulnerable. Maps are continually updated based on improved elevation data (e.g., lidar), storm and flood modeling and analysis techniques, and human modifications.	Flooding, storm surge. Although not the focus, may have some usefulness for tsunamis.
Digital Topographic Maps (USGS 2006)	National Elevation Dataset. Elevation data can be useful for many hazards to identify areas that are most susceptible. Additionally, when a high-quality digital elevation model exists prior to an event and data are collected quickly after, deformation analysis can be conducted to determine locales that suffered the most extreme impacts.	Earthquakes, tsunamis, hurricanes, flooding, snow, etc.
Municipal Parcel Maps	Most counties have these. They are useful to quickly identify owners (including contact information) of properties that may be affected by damages to structures. Or they may be needed for access permission in order for a site investigation to be conducted.	All
Hazus (FEMA 2015)	Hazus is a national standard methodology for determining losses for various disasters. It can be useful for planning purposes. Many data layers are available within the Hazus framework.	All

responsibility for inspecting and reporting bridge condition data to the NBI database following the established coding and recording guidelines.

To be most effective, each SHA should have a GIS-enabled version of the NBI that it can use to quickly perform spatial analysis. Similar databases should be developed for other important structures.

Relevant NBI fields are listed in Table 4-3. These should be reviewed for prioritization and to inform the PDA and DDA processes (note that information at the prioritization stage is also useful for the PDA and DDA and information at the PDA stage is also helpful during the DDA stage). If possible, these fields should be readily available during emergency inspections. Such information can be helpful to PDARs and inspectors to determine which damage is the result of the emergency event and what damage already existed on the structure. However, during PDA and DDA, the inspector should primarily focus on the change in condition state of the elements that form the structure. Confirming inventory data is not necessary but can be provided if it does not impede the PDA progress.

4.3.3 Road Networks and Traffic Information

Highway route topologies and traffic information would ideally be established in a GIS database to enable effective updates to inspection routes, when necessary, as well as to provide real-time feedback to inspectors on viable transportation routes. This information should be updated

Table 4-3. NBI fields recommended during assessment stages.

Prioritization	PDA	DDA
5B: Route Signing Prefix	8: Structure Number	21: Maintenance Responsibility
5C: Designated Level of Service	9: Location	31: Design Load
6: Features Intersected	16: Latitude	32: Approach Roadway Width
7: Facility Carried by Structure	17: Longitude	64: Operating Rating
9: Location	27: Year Built	66: Inventory Rating
19: Bypass, Detour Length	28: Lanes On and Under the Structure	92: Critical Feature Inspection
27: Year Built	43: Structure Type, Main	107: Deck Structure Type
28: Lanes on and under the Structure	44: Structure Type, Approach Spans	113: Scour Critical Bridge
29: Average Daily Traffic	45: Number of Spans in Main Unit	
42: Type of Service	46: Number of Approach Spans	
	49: Structure Length	
	58: Deck Condition Rating	
	59: Superstructure Condition Rating	
	60: Substructure Condition Rating	
	61: Channel and Channel Protection Condition Rating	
	62: Culvert Condition Rating	
	71: Waterway Adequacy	
	113: Scour Critical Bridge	

Source: FHWA (2015a).

frequently with information such as road closures due to construction. Online mapping services such as Google Maps could be used as a fallback for those who do not have GIS software.

It is also important to consider traffic volumes when determining critical structures within the transportation network. This information can be used to make informed decisions about establishing alternative routes in the event of closure of a damaged structure. For highly critical structures, one can perform simulations and scenario planning prior to the event. The information is also useful in deciding which structures to allocate resources for retrofit in an effort to mitigate the effects of the emergency event. Further, such information can be of use when deciding whether a structure should be closed since a high-traffic structure that is weakened can be further damaged by heavy traffic volumes while a low-volume structure may be treated differently.

4.3.4 Data Inconsistencies

Inconsistencies within various databases (e.g., NBI and state-owned systems) may exist. These inconsistencies could mislead the emergency response team and delay structural assessments and evaluations. Therefore, it is necessary to cross-validate the information across multiple sources to resolve any inconsistencies prior to the event. All applicable databases should be compiled and cross-referenced in order to ensure an efficient response.

Key Recommendations for Data Infrastructure and Asset Management

- Place QR codes on structures at the earliest convenience (e.g., routine inspections or site visits).
- Identify what data, software, and hardware 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 (e.g., 24-month interval).
- Provide recommendations on improving data collection during bridge inspection and asset management inventories.
- Cross-reference structure databases and resolve inconsistencies.

4.4 Equipment and Resource Infrastructure

During planning, an agency should identify the resources needed during an emergency event and ensure that they are available when and where needed. Inexpensive tools should be prepackaged (see Section 8.3.1 for details) and put together in kits that a PDAR can quickly access. All personnel should be aware that emergency response has the highest priority for resources such as vehicles. Items that are not specifically used for emergency response should be well-maintained, routinely inspected, and fully charged. Additional resources could include bailey bridges, wood for temporary bracing, gas, and charged batteries.

Key Recommendations for 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 tablet software and databases and how often they should be updated.

4.5 Emergency Event Planning

Emergency event planning for highway structures is a detailed and comprehensive process. Figure 4-1 provides a simplified flowchart for SHAs to categorize the inspection of structures following an emergency event. This flowchart considers the emergency event type, priority inspection lists, lifeline routes, and structure vulnerability. It is recommended that each agency establish its own version of this event plan.

4.5.1 Identify Emergency Events

Each SHA should first identify the emergency events that are most likely to affect its state and plan accordingly. Chapter 2 in this manual describes common emergency events and their likely impacts. Mitigation efforts should consider the type, frequency, and extent of the event in order to prioritize the response planning.

4.5.2 Develop Priority Lists/Routes

Each SHA should develop a prioritized list of structures that need to be inspected in order to minimize disruption to the transportation network and ensure that the traveling public can safely travel. This could be done at the district/regional level. In some states, it may make sense to utilize existing routes for maintenance such as snow removal.

4.5.2.1 Identification of Lifeline or Priority Routes

Lifeline routes are critical links in the highway system that connect important infrastructure such as utilities, hospitals, and schools. It is critical that these routes be serviceable as they are needed to provide essential services during the first 72 hours following an emergency event.

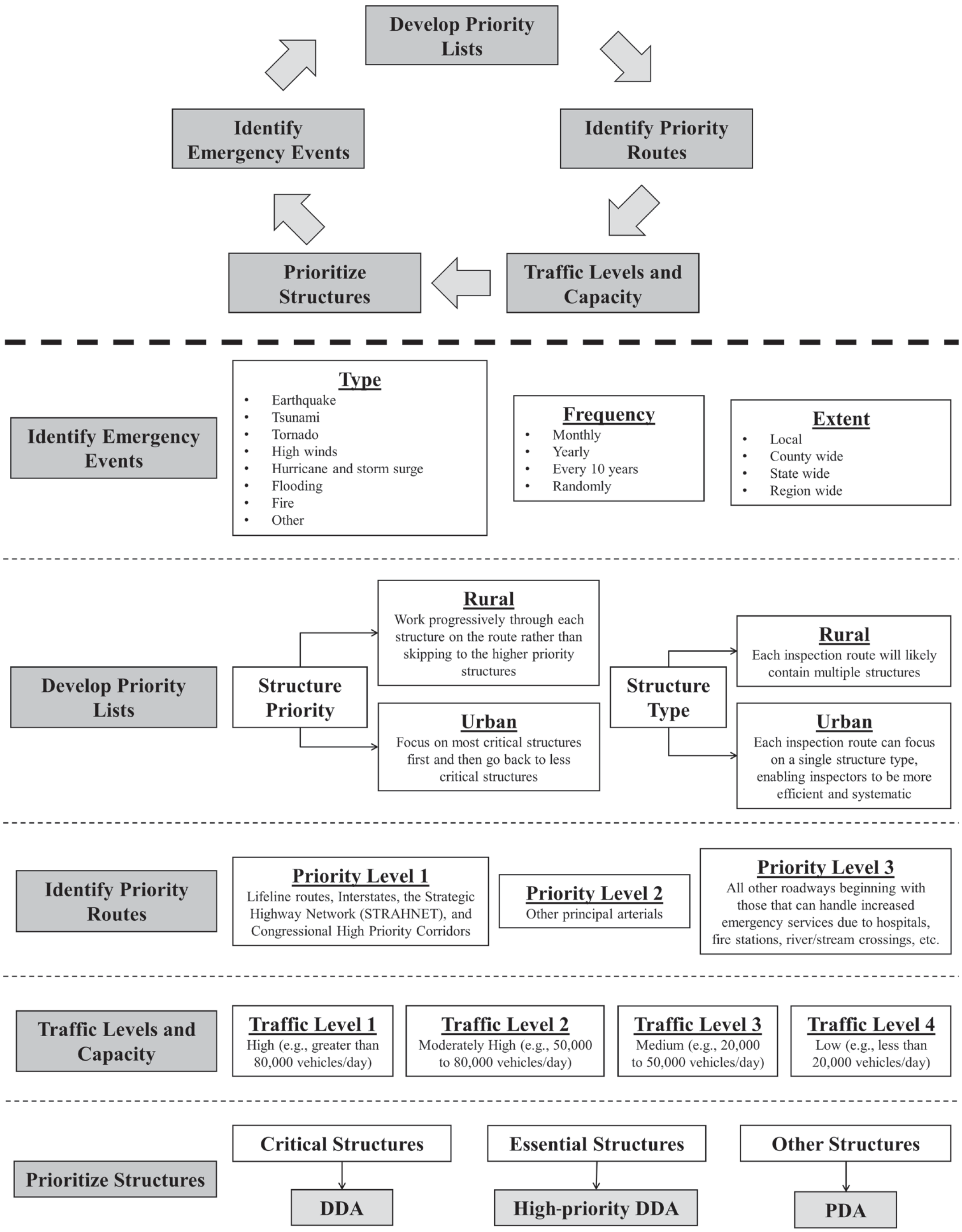


Figure 4-1. Event planning flowchart.

Based on a report conducted by Oregon DOT, the three main goals identified for Oregon seismic lifelines routes are as follows (CH2M Hill 2012):

1. Support survivability and emergency response efforts immediately following an emergency event.
2. Provide transportation facilities that are critical to life support functions for an interim period following an emergency event.
3. Support statewide economic recovery.

These three goals help identify high-priority routes that will be heavily used immediately after an event as well as long-term during economic recovery. These routes typically will have high traffic volumes and provide access to critical facilities such as hospitals, fire stations, airports, and emergency response staging areas. They also serve as evacuation routes when necessary. These routes should be identified prior to the event and plans made to give them top priority during the response effort. Once identified, these structures can be prioritized for retrofit or strengthening during the preparation phase.

Each highway and major structure in the network should be prioritized based on its importance to the transportation network as well as for use in post-event recovery operations. Table 4-4 presents priority levels for routes based on systems developed by Utah DOT, NYSDOT, and Oregon DOT to identify lifeline-critical routes.

4.5.2.2 Prioritization of Structures

Once lifeline routes are established, critical structures on or above those routes can be identified. Structures such as high-traffic bridges and tunnels classified as critical should be marked as high priority for DDA. Essential structures should be marked as high priority for PDA. NYSDOT presents a detailed process for prioritizing these structures for detailed assessments; however, a similar process can be used for the PDA stage (see Table 4-5). Once these structures are identified, the amount of resources required can be estimated based on each of the response levels.

Response for structures identified as highly critical should be discussed regularly with various stakeholders who may need to utilize that structure for their response tasks or transport in emergency situations. However, for ordinary structures, a scoring system can help with the prioritization. The following are two example prioritization scoring systems:

- NYSDOT developed a computer application to use in Microsoft® Access™ for determining structural prioritization (O’Connor 2010).
- WSDOT has developed a methodology for calculating a priority index for each structure: *An Emergency Response Plan for Bridge Management* (Reed and Wang 1993). This plan also contains tables showing the number of bridges and number of team leaders needed.

When an event occurs, the managing engineer should update the prioritization lists based on the best available information.

Table 4-4. Route priority levels.

Priority Level	Description
1	Lifeline routes, Interstates, the Strategic Highway Network, and Congressional High Priority Corridors
2	Other principal arterials
3	All other roadways beginning with those that can handle increased emergency services due to hospitals, fire stations, river/stream crossings, etc.

Source: Modified from Oregon DOT (2014) and Utah DOT (2014b).

Table 4-5. List of features or information sources that can be used to prioritize structures for PDA.*

Feature	Considerations
Initial information	Initial reports from Fast Reconnaissance including the media or the general public will help narrow down where damage is most intense and which structures have experienced major damage or collapse.
Structural vulnerability	This includes the year the structure was built and design criteria. Structural characteristics that increase the likelihood of failure from an earthquake (and other hazards) include superstructure discontinuities (simply supported spans instead of a superstructure with continuity), skew angle, bearing type and height, lack of lateral bracing, deteriorated condition (as reflected in the condition ratings especially the primary and secondary structural members), seat length and width, lack of restraint from lateral displacement, vulnerable structure type (e.g., trusses), redundancy, poor seismic detailing of concrete reinforcement, etc.
Anticipated mode of failure	In planning analyses, one can identify likely modes of failure for critical structures and assess their impacts to determine how catastrophic the failure of that structure would be.
Geological conditions	Structures close to rivers and in other areas with granular soil and high water tables can be damaged from liquefaction including settlements and lateral spreading. Structures close to unstable slopes or near active landslides should also be given high priority. In the case of flooding, sites with expansive or collapsible soils can also lead to higher levels of damage.
Condition	Any structure will deteriorate with time due to exposure to elements and fatigue from repeat loading, degrading structural capacity. Structures that are operating well beyond their design life could also be more vulnerable. However, repairs and modifications could also have been made. Note that these ratings and databases can often change regularly since deficient structures will likely be placed in high priority for repairs. The Recording and Coding Guide for Bridges denotes fields 58–60 as condition ratings for deck, superstructure, and substructure, respectively (FHWA 1995).
Elements	In addition to the overall structure condition, some elements may be in poor condition and could be the weak link with the additional loading from an emergency event.
Traffic levels	Structures with higher traffic levels normally should be given higher priority. The traffic level can be measured by the annual average daily traffic. Highways with links to critical infrastructure (hospitals, fire stations, etc.) should be given higher priority.
Detour availability and impacts of road closures	How does this structure fit in with the network? Structures on routes with few or long detour options available should be given higher priority.
Structure use	In addition to carrying traffic loads, some structures will also support vital utilities such as power lines and pipelines. These structures should be given higher priority. Additionally, some structures may be important for utility access.
Construction Projects	Both current and near-future construction projects should be considered in the prioritization since they will affect the traffic network.

*These considerations are not all-inclusive and are meant as a starting point.
Source: Modified from O'Connor (2010).

4.5.2.3 Fragility-Based Earthquake Damage Rating for Bridge Structures

For earthquake planning and response, two main software tools have been developed: REDARS by the California DOT (Caltrans) and ShakeCast by USGS. These tools can be used to find most vulnerable bridges and roadway segments. These tools make use of fragility curves, which estimate the probability that a structure will meet or exceed a particular level of damage, particularly for bridges during an extreme event. Several SHAs have already developed these fragility curves, especially for earthquake loading. Other SHAs may need to develop these for incorporation in local design practices. Hazus-MH also provides procedures that examine bridge and tunnel vulnerabilities in the event of a seismic, tsunami, or flooding event (for bridges only) (FEMA 2010a; FEMA 2009). A GIS database of bridges and tunnels is also provided by Hazus-MH for SHAs that do not have their own system.

4.5.3 Traffic Levels and Capacity

When prioritizing routes for PDA of highway structures, traffic levels and capacity need to be considered to ensure that the highway network remains as efficient as possible for orderly evacuation, transport of supplies, and quick return to day-to-day activities for a healthy economy. The following measures related to traffic levels have been used for different assessment purposes: highway functional classification, capacity, congestion, emergency access route, and interdependent lifelines.

The traffic level represents the amount of traffic that a highway facility carries on a normal day. There are different performance measures to capture the ranges of traffic levels such as ADT and AADT, the unit of these measures is typically expressed as vehicles per day. Considering the other criteria mentioned in the previous section and the facility types, ADT and AADT are the most-used measurements to address traffic stress levels on the facility. This information is readily available on all major roads for most transportation agencies since it is critical to a variety of transportation engineering activities.

In many cases, these data are presented as AADT traffic flow maps where information is collected via automatic traffic recording systems by state DOTs. These automated systems can also help throughout the assessing, coding, and marking process in a variety of ways. First, they can be monitored after the event to determine which highways have additional capacity to direct traffic to and which are overloaded. They can be useful to adjust PDA prioritizations once bottlenecks have been identified. They can also help route PDARs between structures more efficiently.

In addition to AADT, another criterion to consider is the percentage of heavy vehicles in the general traffic composition; however, such information may not be as readily available.

For general purposes like highway inspections and assessment, agencies can categorize highway structures based on their estimated AADT level as follows (Rotherham Metropolitan Borough Council 2014):

- Traffic Level 1: greater than 80,000 vehicles/day (high)
- Traffic Level 2: 50,000 to 80,000 vehicles/day (moderately high)
- Traffic Level 3: 20,000 to 50,000 vehicles/day (medium)
- Traffic Level 4: less than 20,000 vehicles/day (low)

As an example of a more complex system, Table 4-6 shows the categories recommended by Oregon DOT to analyze their highway facilities.

For additional examples of traffic level integration, refer to Appendix C.

Table 4-6. Example AADT traffic levels.

Levels	AADT Range		Color
1	0	1,000	
2	1,001	2,500	
3	2,501	5,000	
4	5,001	10,000	
5	10,001	15,000	
6	15,001	20,000	
7	20,001	30,000	
8	30,001	50,000	
9	50,001	75,000	
10	75,001	+	

Source: Oregon DOT (2015).

Key Recommendations for 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.
- Identify highways based on their attributes and functional classification.
- Identify traffic levels such as ADT and AADT.

4.6 What-if Analyses

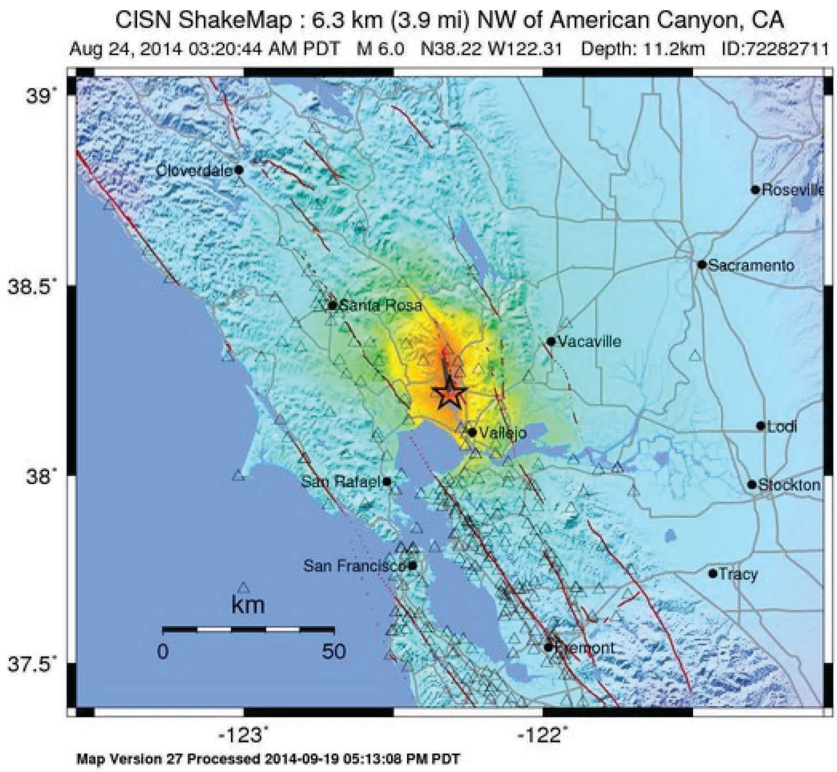
Agencies such as USGS and NOAA have produced tools for predicting intensities of emergency events throughout the United States. This information can be useful in performing what-if analyses and identifying vulnerable structures. These what-if-analyses should consider the maximum credible events as well as more frequent, but lower intensity events. This scenario event planning can be useful to identify lifeline routes as well as more specific vulnerable sections of highway and structures for route prioritization. The following examples are provided by USGS and are for earthquake events. Although these are only for earthquakes, they provide a general outline on procedures and tools that are useful for emergency response what-if analyses.

ShakeMap and ShakeCast, potential tools that can be used for this analysis, can be used both in the pre-planning process as well as the post-event response process:

- ShakeMap (Figure 4-2) provides near-real-time maps of ground motions and shaking intensity after a significant earthquake (USGS 2014d). This information combines readings from seismographs, and crowdsourcing. In areas with high seismicity, historic maps can be used for planning purposes. In other areas, scenario maps can be created considering likely ground motions, source parameters, and geologic setting.
- ShakeCast (Figure 4-3) is a tool for automating ShakeMap delivery to important users as well as identifying individual structures that have experienced high levels of shaking (USGS 2014c). This output is typically received within 10 minutes. It includes a map showing areas with strong ground motions as well as a list of structures that could have been damaged. The list is not all inclusive but, rather, an initial estimate of potentially damaged structures that should be verified by field assessments.

Prior to an event, the following steps [modified from Utah DOT (2014a) and Wald et al. (2008)] should be completed by each agency:

- Support the USGS in developing ground motion models and test earthquakes for production of scenario maps
- Import relevant bridge data (e.g., NBI, fragility curves) into ShakeCast including
  - Year built [NBI field 27]
  - Angle of skew [NBI field 34]
  - Bridge type (kind of material, type of design and/or construction) [NBI field 43]
  - Number of spans [NBI field 45]
  - Maximum span length [NBI field 48]
  - Total bridge length [NBI field 49]
  - Bridge width [NBI field 52]
- Create an email notification list
- Evaluate scenario ShakeMaps to test ShakeCast
- Identify probable associated bridge damage and structures that are highly vulnerable

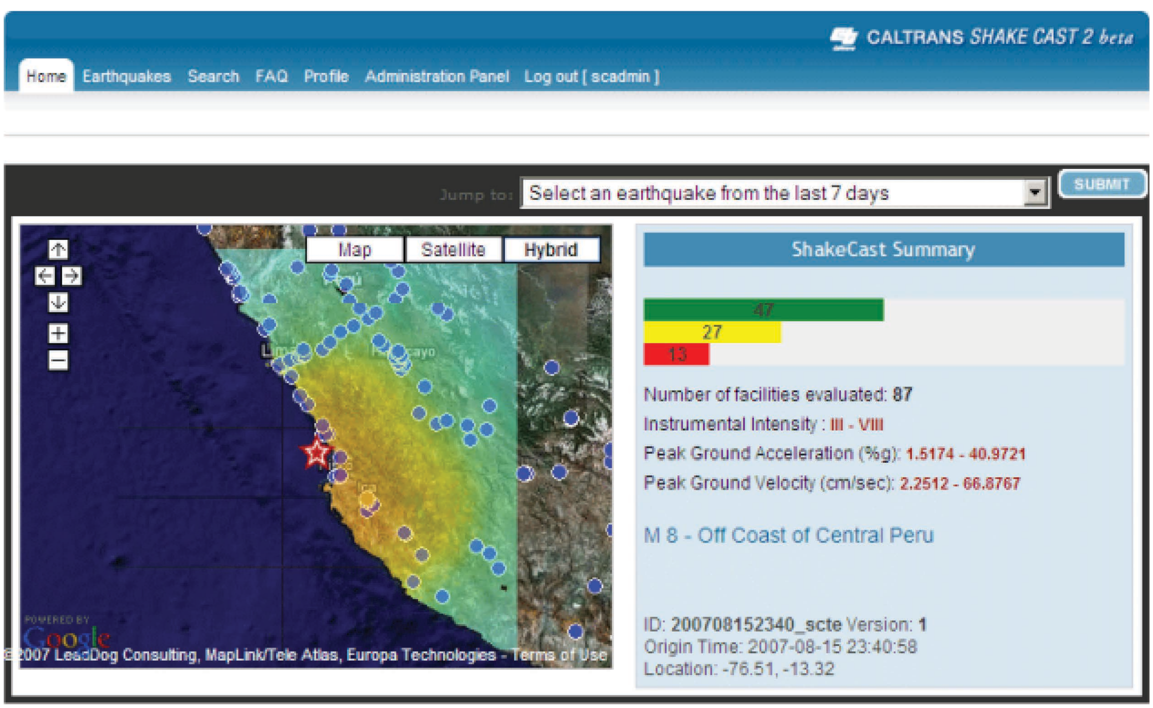


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Source: USGS (2014d).

Figure 4-2. ShakeMap of M6.0 earthquake in California on August 24, 2014.



Source: USGS (2014c).

Figure 4-3. Sample ShakeCast output.

These products produce an estimate of ground shaking intensity only. Researchers (Zhu et al. 2014) are working on tools that will enable cascading hazards such as liquefaction, lateral spreading, settlement, and landslides that can be incorporated into the ShakeCast engine. After the event, the SHA can modify their inspection routes based on the output from ShakeCast.

Key Recommendations for 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.

4.7 Preparation for PDA Responders

Several preparatory steps [modified from Arkansas DOT (2008)] can help an inspector be ready for emergency response:

- Driving inspection routes regularly (annually)
- Visiting reporting stations or local offices (annually)
- Identifying alternative driving routes
- Familiarizing oneself with major river crossings (annually)
- Periodically verifying supplies (e.g., quarterly)
- Keeping up-to-date maps

Key Recommendations for Preparation for PDA Responders

- Familiarize PDARs with their routes.
- Identify alternative PDAR routes.
- Establish a list of personnel that can be used for emergency response.

4.8 Training

These procedures and methodologies will only be as valuable as the people who are implementing them. One of the keys to the success of these efforts is frequent and effective training, which will ensure that the procedures can be implemented quickly and remain applicable over time by all agencies involved in emergency response.

This section provides recommendations for different types of training and intervals that need to be considered when developing an effective training program. This training should be attended by key personnel as well as backup personnel. In addition, a variety of training materials are available on the TRB website (www.trb.org) to supplement information presented in this manual and in *Volume 3: Coding and Marking Guidelines.*

Attendance by personnel from local, state, and federal agencies can also be effective in helping improve coordination.

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 the training materials developed as part of this research that focused on structures are much narrower in scope, it is recommended that they be implemented in a framework consistent with those recommendations in *NCHRP Synthesis 468.*

4.8.1 Formal Training

Formal training processes (and potentially certification) are important to ensure that everyone is aware of the overall program and understands their role in emergency response. The following types of training are recommended:

- *General* training for all relevant employees who will interface with PDARs in some capacity (e.g., GIS, IT, or logistics staff). This could include personnel from other agencies, as needed. This training provides a high-level overview of the process so that they are informed as to what the PDARs will be doing and how to best assist them.
- *Basic* PDAR training for personnel designated to perform PDAs (e.g., maintenance and operations personnel, design engineers). This training covers how to perform PDA evaluations as well as how to transition the results of the PDA stage to the DDA stage. The training includes more specific information on how to use the assessment flowcharts, provides illustrative case study examples, presents the coding and marking procedures, and describes integration of the PDA process into the DDA stage. This training can be conducted as annual offerings of detailed (e.g., full-day) workshops for new employees as well as one-hour refresher courses attended annually. Note that refresher courses could be offered quarterly to encourage and better accommodate participation. These refresher courses can help reinforce the concepts of the PDA process as well as types of damages that can occur. It also helps the PDARs be better prepared mentally for a potential event.
- *Specialized* training modules for managing engineers, EMCs, emergency data coordinators, chief engineers, DDA inspectors, and EI inspectors to be performed frequently (yearly). This training provides an overview of all stages in emergency response with a focus on both the preparation and FR stages. Examples are provided to help show the prioritization process as well as how to improve interdepartment and interagency coordination.

When basic and/or advanced technologies are planned to be used in damage assessments, it is important that the PDARs and inspectors are fully versed in how to use that technology to complete their jobs. Ideally, they would regularly use that technology in their day-to-day duties. However, in the event that they do not regularly use the technology, periodic refreshers may be necessary to make sure that they are able to collect the appropriate data.

4.8.2 Mock Scenarios

Mock events and ground-truthing exercises are an effective approach to test response procedures and provide PDARs and inspectors with field experience under non-threatening conditions. For example, California and other states have completed ShakeOut earthquake drills (e.g., http://www.shakeout.org/california/) to help prepare for response to earthquakes. During these events, inspection teams can become familiar with their route and structures, verify that inspection routes are effective, identify potential hazards, identify potential solutions, and overall become more prepared and comfortable with their roles and duties. Further, communication and coordination procedures can be tested to verify that the response is carried out in an organized, effective manner. Following the mock scenarios, leadership should meet to discuss the results so that they can identify solutions and have them in place before the next emergency event. Budget and logistics should be considered when determining the frequency and scope of these events. They are recommended to be conducted at a minimum of every 5 years. However, several state agencies have already integrated these events into their standard practice, conducting “ShakeOuts” once a year.

4.8.3 Implementation of the Assessment Process and Integration with Routine Inspections

The assessment process following emergency events will be more effective if it is integrated with routine inspections (e.g., NBIS). As such, pertinent structural data and photographs should be collected during routine inspections and made available to the PDARs for emergency events.

4.8.4 Training Immediately After Event

Once an emergency event has occurred and PDAR teams have been assembled, a quick refresher course (approximately one-half hour in length) should be given prior to sending the teams out in the field. This course should not elaborate on details but should cover the most critical components of data collection and overall status of the emergency response, and provide PDARs with any pertinent event-specific information. A quick refresher module is available with the other training materials developed as part of this research.

Key Recommendations for Training

- Review training information in *NCHRP Synthesis 468.*
- 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.

4.9 Communication, Coordination, and Preparation

Intra- and interagency coordination and communication strategies need to be established during planning for effective response. These procedures will be discussed in more detail in Chapter 7. SHAs and other agencies have diverse organizational structures and it is important to consider these when developing an ERP.

Contact information should be updated frequently, preferably as a live database/document on a network accessible to everyone.

Key Recommendations for Communication, Coordination, and Preparation

- Establish intra- and interagency communication protocols and strategies.
- Update contact information regularly.

4.10 Important Emergency Management References

The following is a list of other documents that deal with emergency management and/or response that are useful in preparing and improving ERPs:

- Multiagency Coordination System (MACS)—The MACS is a process that allows all levels of government and disciplines to work together [Department of Homeland Security (DHS) 2008]. The MACS is detailed in the NIMS on pages 64–69.

- *National Infrastructure Protection Plan* (NIPP)—The NIPP provides a coordinated approach to established national priorities, goals, and requirements for critical infrastructure and key resources protection (DHS 2013a).
- *National Preparedness Guidelines*—The purposes of these guidelines are to organize and synchronize national efforts to strengthen national preparedness, guide national investments in national preparedness, incorporate lessons from past emergency events, facilitate a capability-based and risk-based investment planning process, and establish readiness metrics to measure progress (DHS 2007).
- *Comprehensive Preparedness Guide 201: Threat and Hazard Identification and Risk Assessment Guide* (CPG 201)—CPG 201 describes a four-step process for developing a threat and hazard identification and risk assessment (THIRA) and provides communities with additional guidance for conducting one (DHS 2013b).
- *NCHRP Report 525: Surface Transportation Security, Volume 6: Guide for Emergency Transportation Operations*—This guide supports development of a formal program for the improved management of traffic incidents, natural disasters, security events, and other emergencies on the highway system (Lockwood et al. 2005).
- Presidential Policy Directive (PPD) 8: National Preparedness (issued March 30, 2011; replaced Homeland Security Presidential Directive 8 issued December 17, 2003)—This document describes the way federal departments and agencies will prepare for an incident. It requires the DHS to coordinate with other federal departments and agencies and with state, tribal, and local governments to develop a National Preparedness Goal (DHS 2011).

Key Recommendations for Important Emergency Management References

- Familiarize yourself and other appropriate individuals with national standards.
- Review all applicable references.
- Familiarize the agency with PPD National Preparedness guidelines.

CHAPTER 5

Assessment Process

5.1 Assessment Stages

Highway structures will be assessed during an emergency situation using a four-stage process: Fast Reconnaissance, Preliminary Damage Assessment, Detailed Damage Assessment, and Extended Investigation. The primary scope of this document is to address 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, these stages will be briefly introduced, but detailed methodologies will not be presented herein.

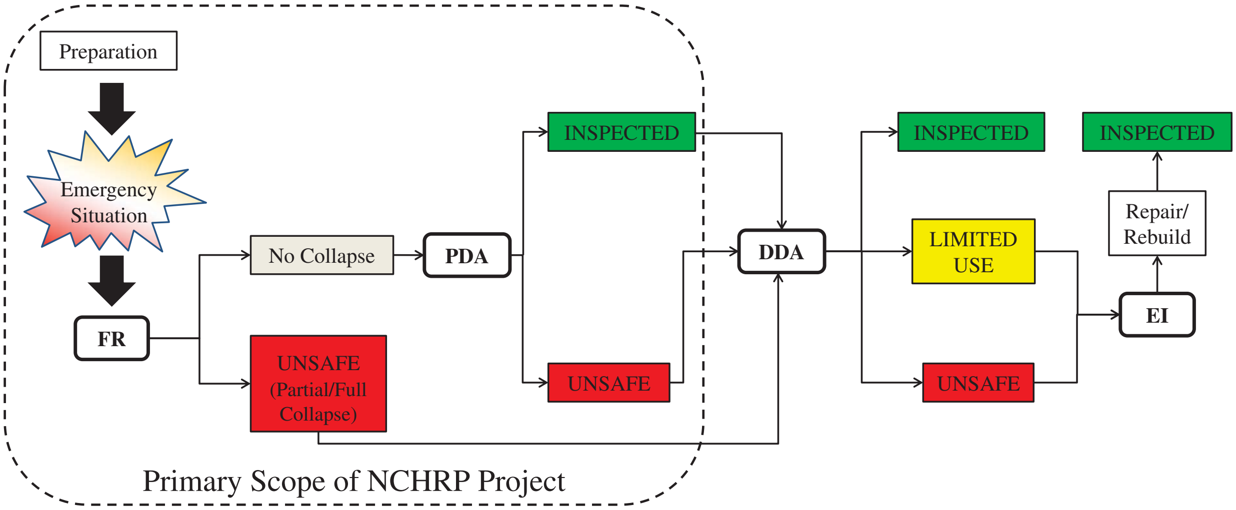
These four stages, described in the following sections, are based on methods currently in use throughout the United States (ATC 1995, 1; O'Connor 2010; Reed and Wang 1993). This multi-tiered approach is aimed at making best use of the limited resources with the appropriate skill and expertise, while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

Figure 5-1 diagrams the assessment process for a single structure and the interaction of the assessment stages along with the possible marking classifications for a structure. The marking classifications are described in detail in Section 6.1. Table 5-1 summarizes the objective and primary deliverables of each assessment stage.

5.1.1 Fast Reconnaissance

The objective of the FR stage is to quickly provide a global perspective and to establish/update the extent of the damage region as necessary. This work needs to be completed both in the office and in the field. While FR should be completed at all response levels (see Section 5.2), 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. Descriptions of five possible FR methods follow:

- Pre-event or real-time disaster hazard mapping products. For several major emergency events such as earthquakes or hurricanes, pre-event or real-time disaster hazard mapping are often available, which provide the most rapid information indicating potentially severely damaged areas. When available, this information should be used; however, the start of the response process should not wait for this information because the timeliness of the data can vary.
- Rapid remote sensing. Aerial imaging and lidar reconnaissance using helicopters or small fixed-wing aircraft that can quickly be mobilized are most appropriate for higher response levels. For lower response levels, personnel can be designated to drive highway routes (without stopping) to determine the nature and extent of the damage. These crews can utilize global positioning system (GPS) technology to log their routes and document where damage is observed.



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 5-1. Assessment stages and subsequent primary level of coding.

- Crowdsourcing. Live video from SHA cameras or other sources, such as the media or the general public, may be used for an initial assessment on the condition of severely damaged structures.
- Small or micro unmanned aerial vehicle (UAV) based imaging is being considered currently and expected to become a popular approach for hard-to-access disaster areas. Similarly, automated analysis using technologies such as mobile lidar may be used for a quick assessment of the landslide potential of slopes and embankment settlements.
- Detailed FR techniques such as aerial reconnaissance (e.g., helicopter or small fixed-wing aircraft) is strongly recommended only for larger events (e.g., Response Level IV), where the damage is likely to be geographically dispersed.

The information from these technologies can then be combined into a GIS platform where structure databases can be cross-correlated with the incoming damage reports from FR. Inspection routes and priority lists can be updated frequently using this real-time information.

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

5.1.2 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 5-1). It is expected that this stage may take from a few minutes to 30 minutes per structure depending on the type of structure, degree of damage, and accessibility constraints. The 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. 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 preliminary percent damage

Table 5-1. 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).

estimates of the structures, which are used for prioritizing DDA. These estimates also could be used to develop preliminary damage cost estimates for the incident that can be refined with DDA and EI.

It is strongly recommended that a DDA be performed by trained inspectors for every structure that could potentially be damaged by the event despite the decision of the PDA. However, those that are not found unsafe during the PDA can be given a lower priority for the DDA and completed at a later time.

Given the wide variety of damages observed in various types of emergency events, it can be overwhelming to check for every possible type of damage on every element. To simplify the process, the most common types of damages seen throughout the various emergency events are grouped into categories of structural, geotechnical, hydraulic, and special case (see Table 5-2).

Table 5-2. 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

The PDA should be conducted by a team of at least two PDARs. The following list outlines the general PDA procedure to be used for all structures:

1. Upon receiving notification of an emergency event, PDARs review vulnerabilities and common damages for highway structures.
2. PDARs assist in rescue efforts, if necessary.
3. If any hazardous condition is encountered during the inspection, such as downed power lines, faulty traffic control devices, or roadway obstructions, the appropriate authorities should be contacted in order to secure the area.
4. Prior to starting their route, PDARs confirm with each other the division of tasks. Generally, only one team member should fill out a single form for each structure. Both should make observations and be alert to the conditions of the scene.
5. PDARs approach the structure with caution and never walk or drive immediately under, over, or adjacent to the structure until the safety of the environment has been assessed.
6. Each PDAR should remain reasonably separated from each other but remain within visible range at the same time and never go underneath a structure at the same time.
7. When first arriving to a structure site, PDARs take a photograph of the identification tag, a photograph of the overall structure, and GPS coordinates. If available, the QR code on the structure should be scanned. With a smart device and app, these can be completed from the same device.
8. A site visit is estimated to take 15 to 30 minutes to complete. However, if the structure is clearly collapsed and unsafe, PDARs can simply complete the basic elements of the form and move onto the next site after notifying the managing engineer that the structure should be closed. More complex or larger structures will take longer to properly perform a PDA. PDARs should be conscious of the time and make sure that they do not spend too long at a particular site so they can efficiently move through their route.
9. A more detailed process for each structure is written in *Volume 3: Coding and Marking Guidelines* to help quickly walk PDARs through the process. When necessary, PDARs should consult the damage state lists and photographic examples provided in *Volume 3: Coding and Marking Guidelines* to aid in damage state ratings.
10. PDARs look for evidence of disturbance or irregularities such as shifts in guardrails or striping. These are noted on the form.

11. PDARs provide an element damage-level ranking (none, minor, moderate, severe) for all applicable elements of the structure.
12. Once PDA is complete, the PDAR team meets and comes to a conclusion on the overall marking of the structure (INSPECTED or UNSAFE).
13. PDARs fix the placard to the structure in the appropriate location.

Specific considerations for each highway structure are outlined in *Volume 3: Coding and Marking Guidelines.*

5.1.3 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 structural damage level and decisions on use restriction, or the need for an EI (see Figure 5-1). This is a "damage inspection" as defined by the MBE and is not considered a rapid assessment for an emergency situation. It is therefore beyond the scope of this project.

The DDA is included in this manual for completeness and to ensure the overall process is clearly defined as well as to ensure a smooth transition between the inspection stages. The DDA may include a load rating analysis to determine what levels and types of traffic the structure can safely handle. Information to support a load rating analysis includes the structure geometry, member connectivity, and section properties. The DDA is a multi-tiered inspection conducted by specialists (e.g., structural, geotechnical, hydrological, mechanical, materials) and may take several hours or more for each structure using integrated visual inspection and select technologies. DDA photos and reports will be uploaded into an emergency inspection management system or agency equivalent.

Note that DDAs should be conducted for all structures where damage was possible regardless of the outcome of the PDA. However, those with a PDA outcome of INSPECTED should be placed at a lower priority compared with those that were designated as UNSAFE.

5.1.4 Extended Investigation

The EI stage is performed as soon as possible following an UNSAFE or LIMITED USE rating from DDA. This is an "in-depth inspection" as defined by the MBE and may also include a "special inspection" or an "underwater inspection." The EI is not considered a rapid assessment for an emergency situation and is therefore beyond the scope of this project. The EI would also likely entail specialized technologies. Reporting of the findings from an EI follows the NBIS and other standard SHA operations.

Although this stage is not within the scope of this project, 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. Follow-on inspections, emergency repairs, and testing would be conducted by more experienced professionals using more sophisticated technology than what the PDA and DDA would support.

In the case of an earthquake, structures may survive the first event but become more vulnerable for aftershocks. Hence, continued monitoring and repeat checks may be needed. In most cases, these aftershock checks would involve a repeat of the PDA and DDA. Further, it is important to keep investigations in context of the longer-term safety and economic impacts so that the agency can integrate this with its priority ratings to determine when repairs and replacements should be made.

5.2 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., M7.0) creating damage over a dispersed geographic region will require a different method of response for structural assessment compared to a smaller event (e.g., M4.0 earthquake) where damages will be more localized and lesser in magnitude.

Use of these response levels can help an 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.

This manual presents four response levels. Each SHA may 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, an SHA may choose the following strategy to help in their response:

Level I Regular inspectors in the affected region(s) directly proceed to PDAs or DDAs, as appropriate. 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.

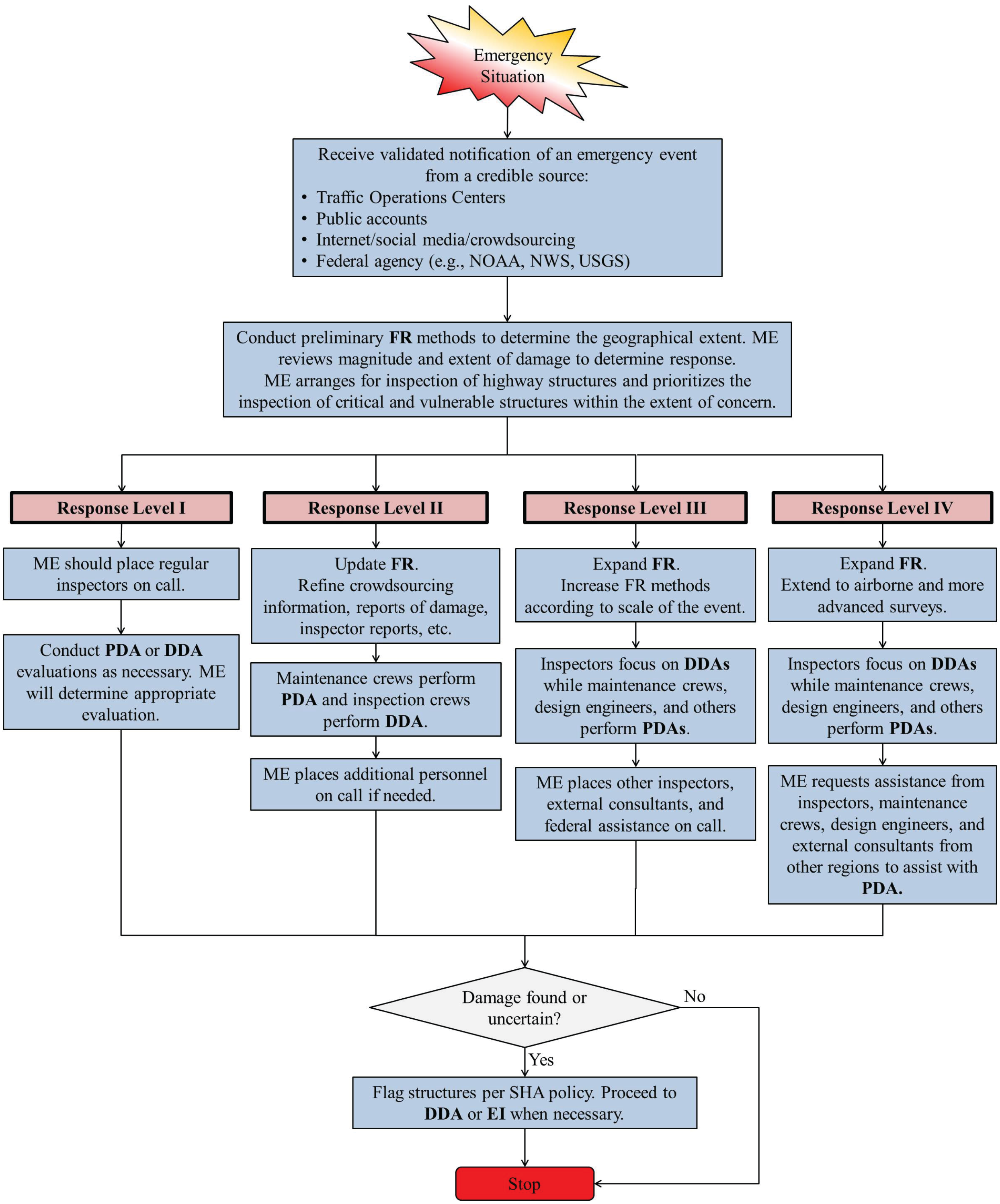
Level III Inspectors focus directly on DDAs, while maintenance crews, design engineers, and others (as needed) in the region are immediately mobilized to perform PDAs. Inspectors from other regions could be placed on call to assist. External consultants from local firms who are appropriately trained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

It should be noted that the response levels defined in this manual are to be used as a reference or a guide for SHAs as they implement these recommended procedures for assessing, coding, and marking vulnerable structures. The selected values for magnitudes defined in each emergency event response can be refined depending on the SHA's experience, local design practice, identification of vulnerable structures, and the intensity levels which have produced damage in past events. In addition, the response levels and their threshold values depend on the resources available and the experience of the SHAs with a specific emergency event. In certain cases, it may make sense for a specific SHA to add additional response levels or remove a level, if locally it is found to be a more reasonable approach. For example, SHAs in Alaska, Washington, Oregon, and California would likely use different earthquake magnitudes than those presented due to the higher level of seismic design standards and seismic activity.

While it is important to be conservative in judgment when determining the appropriate response level, over-conservative calls to action may impede future efforts. If too many PDARs are allocated, this may lead to delays in design and construction for projects that will help improve resilience in the future and may be of a higher priority than the emergency event. False warnings and overemphasis can also numb people's response to future events.

Figure 5-2 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



ME = Managing Engineer

Figure 5-2. Response level process flowchart.

severity and geographic extent of the emergency event. Upon receiving an emergency notification, emergency management officials should first validate it. Once the notification has been confirmed, structure priority routes should be reviewed and planned for inspection. Response levels corresponding with 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

5.2.1 Earthquake Response Levels

Magnitude and source-to-site distance are metrics that are highly correlated to the intensity of ground shaking. Other local effects, such as soil type in the vicinity and under the structures, and structure and foundation type, are also important parameters that affect the structure's response. Nonetheless, both magnitude and source-to-site distance are well-accepted global metrics for determining the extent of damage to which response levels can be tied. However, there are no absolute boundaries in an emergency incident and these intensity and distance metrics provide a starting point for mobilizing a response that can be refined as feedback becomes available from field crews.

Table 5-3 illustrates the four response levels for earthquake events based on NYSDOT (O'Connor 2010). The intensity metric of the incident (i.e., earthquake magnitude) and the distance metric of the structure to the characteristic point (e.g., epicenter) are used in differentiating response levels. For example, for a M4.0 earthquake, the majority of the damage is anticipated to occur within a 40-mile radius of the epicenter. Given different seismic levels and seismic design standards, the magnitudes below are categorized by seismic design category.

Several factors influence earthquake impacts; therefore, considerations are provided to better estimate the appropriate response level needed in the event of an earthquake:

- The radius of concern should not be considered an absolute boundary during inspections. If any damage is observed outside of the given radius, increase the radius by 5 miles until no damage is found.
- Site-specific intensity measures are useful parameters to determine the severity of damage.

5.2.2 Tsunami Response Levels

The proposed tsunami response levels are based on NOAA's warning system for Hawaii, which uses earthquake magnitude and location as proxies for tsunami intensity (NOAA/NWS 2014f). NOAA provides warning systems for the Pacific Ocean and the Caribbean Sea as well. Other parameters, such as local bathymetry, on-shore topography, and urban fabric, affect the maximum inundation and tsunami flow velocities, which are highly correlated to the degree of damage. Although tsunamis may be caused by other geophysical phenomena such as volcanic eruption and landslides, for purposes of this process manual, the response levels will focus on the most common occurrence of tsunamis, which are typically triggered by significant magnitude earthquakes.

Table 5-4 outlines the typical messages for Hawaii corresponding with earthquake magnitude and location. Tsunami messages include the message type (warning, watch, advisory); location; earthquake origin time, coordinates, depth, location, and magnitude; and evaluation (example in Appendix B.2).

Table 5-3. Earthquake response levels.

Response Level	Earthquake Magnitude		Radius of Concern	Description of Response
	SDC A/B	SDC C/D		
I	$M_w < 3.5$	$M_w \leq 5.5$	na	A broad-based response is not planned or required. If there are reports of damage, the managing engineer will determine if a PDA needs to be done. The managing engineer uses discretion to inspect especially vulnerable or critical structures close to the epicenter.
II	$3.5 \leq M_w < 4.5$	$5.5 < M_w < 6.2$	40 mi	The managing engineer will immediately initiate PDA. All state routes within the residency will be driven according to priority and all structures investigated. Reports of damage or questionable conditions will be called in immediately. Summary reports are to be sent to the managing engineer at the end of each day. If no damage is discovered during PDA, the post-earthquake response can be terminated. DDA will be done on structures within the radius of concern: • Deemed *critically important* by the managing engineer • Following an UNSAFE rating from PDA • Where evaluation by a more trained or experienced person is needed If there are reports of structural damage outside of the default radius of concern, the managing engineer will increase the radius and adjust the inspection program accordingly.
III	$4.5 \leq M_w < 5.5$	$6.2 \leq M_w < 6.7$	60 mi	Use the same criteria as Response Level II, but with a larger radius.
IV (High)	$M_w \geq 5.5$	$M_w \geq 6.7$	80+ mi	The state's Incident Command System will be activated for this high-level response to ensure coordination of effort among SHA regions, main office, and other agencies. All available personnel should be mobilized. PDARs will conduct PDA of routes immediately and the managing engineer will arrange for DDA of all critical structures that are within the radius of concern as soon as possible. DDA evaluations should also follow the same criteria presented in Response Level II.

SDC = Seismic Design Category
Source: Based on O'Connor (2010).

Several factors influence a tsunami's impact; therefore, the following factors should be considered when determining a response level for a tsunami event.

- Tsunami inundation and height is highly variable due to local topographic effects. Tsunami waves tend to concentrate in channels or areas of low slope surrounded by high hills, producing higher loads and inundation levels.
- Damage will be extensive in flat, low-lying areas along the coast. Structures located in low, coastal areas surrounded by high cliffs are particularly vulnerable since the tsunami waves will concentrate in these channels.
- Wave heights measured off shore can be much lower than what is seen on the coast due to amplification as water depths reduce closer to the coastline.
- Prior to the tsunami reaching coastline, wave amplitude can provide an estimate to the anticipated tsunami size. However, following the tsunami impact, actual inundation levels should be refined and used to determine appropriate response levels.
- Initial impact from tsunami waves create only part of the damage. Wave recession and drawdown can take hours and generate additional loading on highway structures.

Table 5-4. Tsunami response levels for Hawaii.

Response Level	Event and Message Type	Earthquake Magnitude	Tsunami Amplitude	Description of Response
I	Local (Local Tsunami Information)	4.0–6.8	< 4 in.	The managing engineer will monitor any cases of tsunamis reaching shorelines within the messages provided by NOAA. In the event of a tsunami, the managing engineer will initiate inspection of highway structures using PDA based on inundation levels. If it is confirmed that there is no tsunami reaching on shore, no highway structures need to be inspected unless there is strong ground shaking due to the earthquake.
	Distant (Tsunami Information)	6.5–7.8		
II	Local (Local Tsunami Information)	4.0–6.8	4 in.–3 ft	NOAA warning messages will provide the location, coordinates, and arrival time of the estimated tsunami wave. Once a tsunami warning is issued, the managing engineer should plan PDA routes in the affected area. If there is confirmation that a region was hit by a tsunami, and only after the tsunami warning has been listed, the managing engineer will initiate PDA of highway structures. If no damage is discovered during PDA, the response can be terminated. As the inundation decreases from the coastline, structures should be evaluated based on the discretion of the managing engineer. In events of prolonged flooding, structures should be evaluated.
	Distant (Tsunami Advisory)	≥ 7.9 and ETA > 6 h		
III	Local (Urgent Local Tsunami Warning)	6.9–7.5	3 ft–10 ft	The managing engineer will monitor NOAA messages for the tsunami locations and arrival times. Inspections should only begin after the tsunami drawdown subsides. Tsunamis of this intensity are expected to occur over a vast area of coastline. SHAs may or may not have the personnel and resources to perform structural assessments. If there is a lack of resources, SHAs shall request assistance from federal agencies. Highway structures may have damage from not only the initial tsunami impact, but also the drawdown of the wave. Geotechnical and structural damage should be assessed using PDA of all highway structures located within the inundation zone.
	Distant (Tsunami Watch)	≥ 7.9 and ETA 3–6 h		
IV (High)	Local (Statewide Urgent Local Tsunami Warning)	≥ 7.6*	> 10 ft	The managing engineer will verify affected coastal regions within NOAA messages. Detailed FR will take place to estimate the geographical extent of damage. Statewide tsunamis will likely impact all the entire state of Hawaii. All regions involved will activate the Incident Command System to ensure coordination with federal agencies. This event will require all available SHA inspectors, personnel, and resources.
	Distant (Tsunami Warning)	≥ 7.9 and ETA < 3 h		

ETA = Estimated time of arrival.
*Local earthquakes with magnitudes higher than 7.6 have the potential to cause wave heights and/or inundation levels to exceed 30 ft.

- Local earthquakes of relatively lower magnitudes may generate a tsunami causing more damage than a larger magnitude earthquake with the epicenter farther away.
- Runup and damage due to a tsunami are related to the phase of the tide when the tsunami impacts.

5.2.3 Tornado and High Wind Response Levels

For purposes of this process manual, tornado and high wind events are grouped together for simplicity. High wind events are those with wind speeds ranging from 1 to 73 mph and are defined by the Beaufort scale (NOAA/NWS 2014d). High wind events are likely to occur over a local area with wind speeds varying by location. The NWS offers high wind watch/warning and wind advisory notifications (NOAA/NWS 2014g). All of the wind notifications are issued by local NWS Forecast Offices.

Tornados are classified by the EF scale and have wind speeds from 65 to over 200 mph (NOAA/NWS 2014c). The EF scale rates the intensity of the tornado from EF-0 to EF-5 based on the damage of structures and vegetation on the tornado path. The official EF rating is often determined after ground-based or aerial damage surveys which may occur a couple of days after tornados. However, preliminary estimates about the EF rating of a tornado and the size of affected areas can be made following inspection flights right after a tornado, which can help managing engineers to estimate the required level of response. Tornados themselves develop fairly quickly which makes it difficult to provide an accurate warning system.

Table 5-5 outlines the proposed response levels for tornado and high wind events. High wind and tornado events can cause varying levels of geographic damage; therefore, the following considerations should be used when determining response levels.

- High wind events will typically occur over a local geographic area whereas tornados will typically follow a path.
- Tornado events have the potential to cause large amounts of wind-borne debris. Although damage from wind may be minor, debris can cause severe damage.
- EF ratings refer to damage at particular locations and not necessarily the damage over the entire tornado path or the size of affected areas. However, generally tornados with higher intensity can be expected to impact a larger area. When planning for the level of response, both the tornado EF rating and the size of affected areas must be considered.

5.2.4 Hurricane Wind Event Response Levels

Hurricane intensity is defined by the Saffir–Simpson hurricane wind scale with wind speeds exceeding 74 mph (NOAA/NWS 2013). Hurricane wind events can occur over a vast region of land or be confined to coastline near the hurricane. Table 5-6 highlights the proposed hurricane wind response levels.

Table 5-5. Tornado and high wind response levels.

Response Level	Wind Speed (Scale)	Length of Impact	Description of Response
I	32–64 mph (B7–B11)	Local	The managing engineer will monitor wind-prone structures in locations of wind speeds over 32 mph. These include overhead signs and cable bridges. PDAs will be performed at the managing engineer's discretion.
II	65–110 mph (B12–EF1)*	< 10 mi	In the event of high winds over 65 mph, the managing engineer will initiate PDA of wind-prone structures such as overhead signs and cable bridges. These structures should be inspected for damage caused by wind-borne debris. If an EF1 tornado occurs, the managing engineer will monitor all structures near the tornado path. The geographical extent of an EF1 tornado is difficult to predict but will typically take place over a few miles. SHAs should provide an adequate number of PDARs to perform PDA on all highway structures within the tornado path.
III	111–165 mph (EF2–EF3)*	10–30 mi	All highway structures located in the path of the tornado should be inspected. EF2 to EF3 tornados are likely to cause debris damage so the radius of inspection should be extended from Response Level II. The managing engineer will request federal assistance in the event of a large tornado event that taxes current personnel and resources.
IV (High)	> 166 mph (EF4–EF5)*	> 30 mi	All highway structures located in the path of the tornado should be inspected. EF4 and EF5 tornados are extremely violent and have the potential to lift large debris. It is likely that the radius of damage greatly exceeds the tornado path. The managing engineer will examine the extent of damage to determine an adequate extent of coverage for PDA evaluation. Federal assistance should be requested during EF4 and above tornados to adequately perform all necessary structure assessments.

* EF ratings are not determined immediately after a tornado. These ratings are to be used only once verified after a tornado event.

Table 5-6. Hurricane wind event response levels.

Response Level	Wind Speed (Scale)	Extent of Concern	Description of Response
I	74–95 mph (Hurricane Category 1)	Local	The managing engineer will monitor the development, progress, and location of the hurricane. The managing engineer will initiate PDA evaluation of all highway structures within the hurricane warning area. States affected should work in conjunction providing resources and personnel to any states in need.
II	96–110 mph (Hurricane Category 2)	Regional	Prior to the hurricane making contact with land, the managing engineer should develop a list of critical highway structures within the defined hurricane warning area. As the hurricane develops, wind speeds should be collected and referenced with highway structures.
III	111–156 mph (Hurricane Category 3–4)	Statewide	As the intensity of the hurricane increases to Category 3, a wider inspection radius should be used compared with Response Level II. This response level will follow the same criteria as Response Level II but with a larger radius. In the event of a widespread event, SHAs should request federal assistance for inspections.
IV (High)	> 156 mph (Hurricane Category 5)	Multiple states	In the event of a Category 5 hurricane, all SHAs affected should work in conjunction with federal agencies for necessary assistance. This event will likely be widespread and tax the resources and personnel of the local agencies in charge of structure assessment. It is recommended that a detailed FR be performed in order to estimate the geographical extent of damage. Highway structure locations should be monitored with wind speeds.

Once the event subsides and it is deemed safe, PDA evaluations should begin. Hurricane events can cause varying levels of geographic damage; therefore, the following considerations should be used when determining response levels:

- The geographic extent of hurricanes is difficult to predict. The managing engineer should monitor the path and size of the hurricane to determine the extent of concern.
- Hurricanes can cause wind damage not only along coastlines but far inland as well.
- Hurricane events have the potential to cause large amounts of wind-borne debris. Although damage from wind may be minor, debris can cause severe damage.

5.2.5 Storm Surge Response Levels

Storm surge often occurs over large areas of coastline and can damage highway structures due to repetitive wave loading. Table 5-7 highlights the proposed response levels for this process. Storm surge heights should be referenced with highway structure heights and in any cases where storm surge levels are expected to rise above the highway structure, the structures should be evaluated using DDA.

Several factors influence the impact of storm surge, specifically coastal region. Therefore, the following factors should be considered when determining a response level for a storm surge event (Douglass et al. 2014):

- Regarding bridges, most damage occurs when the storm surge elevations meet or exceed the height of the low chord of the bridge deck.
- Damage can occur due to the impact of debris carried by waves.
- Storm surge events can happen at any time during the year, not only during hurricane events.
- Gulf of Mexico and South Atlantic Coast:
  - Coastlines with a shallow continental shelf can experience large storm surges.
  - Storm surge can vary substantially within the same estuary due to wind.
  - Storm surge wave heights are typically higher to the right of the landfall location.

Table 5-7. Storm surge response levels.

Response Level	Storm Surge Height	Description of Response
I	< 5 ft	The managing engineer will monitor the development, progress, and location of storm surge heights. Storm surge maps should be developed highlighting areas of prolonged exposure to storm surge wave loading. The managing engineer will initiate PDA of all highway structures along the affected coastline. Embankments are particularly vulnerable to erosion. Inspect all bridges that have storm surge heights that meet or exceed the designated design water level using DDA. States affected should work in conjunction providing resources and personnel to any states in need.
II	6–8 ft	Storm surge heights should be collected and referenced with highway structures. All areas of coastline affected by storm surge should be evaluated using PDA.
III	9–12 ft	As the storm surge height increases, the extent of damage is likely going to increase along the coast. This response level will follow the same criteria as Response Level II but with a larger radius.
IV (High)	> 13 ft	In the event of any storm surge heights over 13 ft, SHAs affected should work in conjunction with federal agencies for necessary assistance. Storm surge levels of this magnitude will likely impact large areas of coastline and cause extensive damage that could tax the resources and personnel of the local agencies in charge of structure assessment. It is recommended that detailed FR be performed in order to estimate the geographical extent of damage. Highway structure locations should be monitored with storm surge heights. In any case, when storm surge heights exceed the structure height, following the hurricane, those structures should be evaluated using DDA. Any structure affected by storm surge should be evaluated using PDA.

- Mid-Atlantic and New England Coast:
  – The total water level at the peak of a hurricane storm is based on the astronomical high tide.
  – Storm surge duration can vary drastically in this region.
- Great Lakes Coast:
  – Storm surge can be more significant in bays near the ends of lakes.

5.2.6 Flooding Response Levels

For purposes of this process manual, response levels will focus on river flooding events. The NWS monitors and records areas of minor, moderate, and major flooding. Maps provided by the NWS can be used by the managing engineer to determine the location and severity of flooding. Once a flooding event occurs, monitoring of all highway structures within the defined flooding boundaries is recommended. Table 5-8 highlights the proposed flooding response levels.

Several factors influence flooding consequences; therefore, the following factors should be considered when determining flood response levels (Parola et al. 1998).

- Debris can cause aggravated flow conditions which can contribute to scour.
- Large debris can accumulate where trees grow only on the immediate stream banks.
- Lateral migration of streams and/or stream widening processes may contribute to damage at bridge abutments.

5.2.7 Fire Response Levels

Fire events can be categorized as vehicle or local fire (e.g., gasoline fire) or wildfires. Vehicle fires are typically local in nature and will most likely only affect one structure. Wildfires are less likely to cause damage to highway structures because they often occur in the countryside, but the extent of concern is much larger. Table 5-9 details the proposed fire response levels.

Table 5-8. Flooding response levels.

Response Level	River Flooding	Extent of Concern	Description of Response
I	Near Flood Stage	na	The managing engineer will monitor and track scour-critical structures including bridges and culverts. Highway structures elevations should be mapped and cross-referenced with flood maps in order to estimate the likelihood of flooding near or on any highway structure. It is not necessary to perform PDA evaluations at this time.
II	Minor Flooding (5–10 year recurrence)	Contained to rivers	Highway structures partially inundated should be assessed and evaluated using PDA. If conditions are suitable, PDA may be performed during flooding scenarios. If flooding conditions are not suitable, PDA should be performed immediately following the flooding event. Scour-critical bridges and culverts should be monitored and evaluated using DDA. In the event of any highway structure scour damage, the appropriate scour reference manuals should be used.
III	Moderate Flooding (15–40 year recurrence)	Rivers and close roads	In the event of moderate flooding, the geographical extent may span over several miles. All available SHA personnel and resources should be deployed in order to adequately assess the extent of damage due to flooding. Highway structures that were previously scour critical should be evaluated using DDA. All other highway structures with unknown scour information should be evaluated using PDA.
IV (High)	Major Flooding (50–100 year recurrence)	Determined by severity; likely widespread	Major flooding events will likely tax the resources and personnel of the SHA. When there is a lack of personnel and resources, the managing engineer should request federal assistance. All highway structures that were considered scour critical prior to flooding should be evaluated using DDA. All other highway structures should be evaluated using PDA.

na = not applicable
Source: Based on NOAA/NWS (2014g).

Table 5-9. Fire response levels.

Response Level	Fire Type	Extent of Concern	Description of Response
I	Vehicle fire	Local	The managing engineer will deploy PDARs to proceed to the structure and work with fire officials to determine the severity of the fire. During the fire, the structure should be marked as UNSAFE and appropriate traffic control devices should be in place to detour traffic away from the structure. Once the fire event has subsided, inspection of the structure using DDA should proceed because much of the damage could be internal and difficult to view during a PDA evaluation.
II–IV	Wildfire	Varies	In the event of a wildfire, the managing engineer should work with fire agencies monitoring the fire to determine the extent and severity. GIS mapping platforms should be established and cross-referenced with the fire location in order to determine whether the fire will impact any highway structures. If the fire does make contact with any highway structures, the structure is physically and digitally marked as UNSAFE and inspection is delayed until the fire has subsided. The managing engineer works with traffic operations centers to establish alternative routes for the affected structure. It is crucial to establish appropriate traffic control devices to detour the public away from the structure. Because fire damage is variable in nature, DDA procedures should be used instead of PDA. As the size of the fire increases from local to statewide, the managing engineer continues to monitor all structures within the affected range. The number of personnel and inspectors are increased appropriately.

CHAPTER 6

Coding and Marking Guidelines

6.1 Marking System

A coding and marking system was developed to support uniform communication between PDARs, 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.

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 shall 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 6-1 for the placard and Figure 6-2 for the coding options). For example, the placard with the 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.

Structures shall 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 a decal/sticker with a QR code or have access to a mobile QR code printing machine.

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 name/initials of the PDAR.

After undergoing PDA, highway structures should be posted with one of two placards: INSPECTED or UNSAFE (refer to Figure 5-1). 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 5-1). This posting lets the SHAs, PDARs, 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 posting category are summarized in Table 6-1.

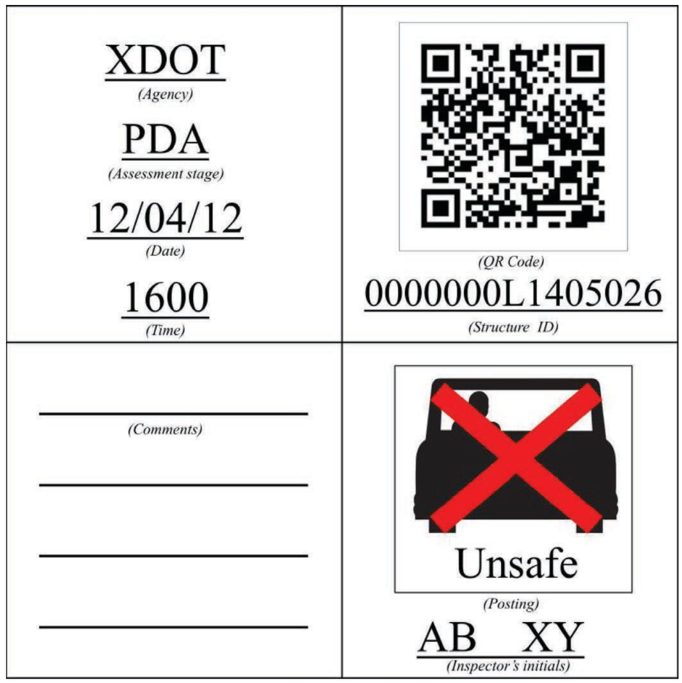


Figure 6-1. Example marking placard.

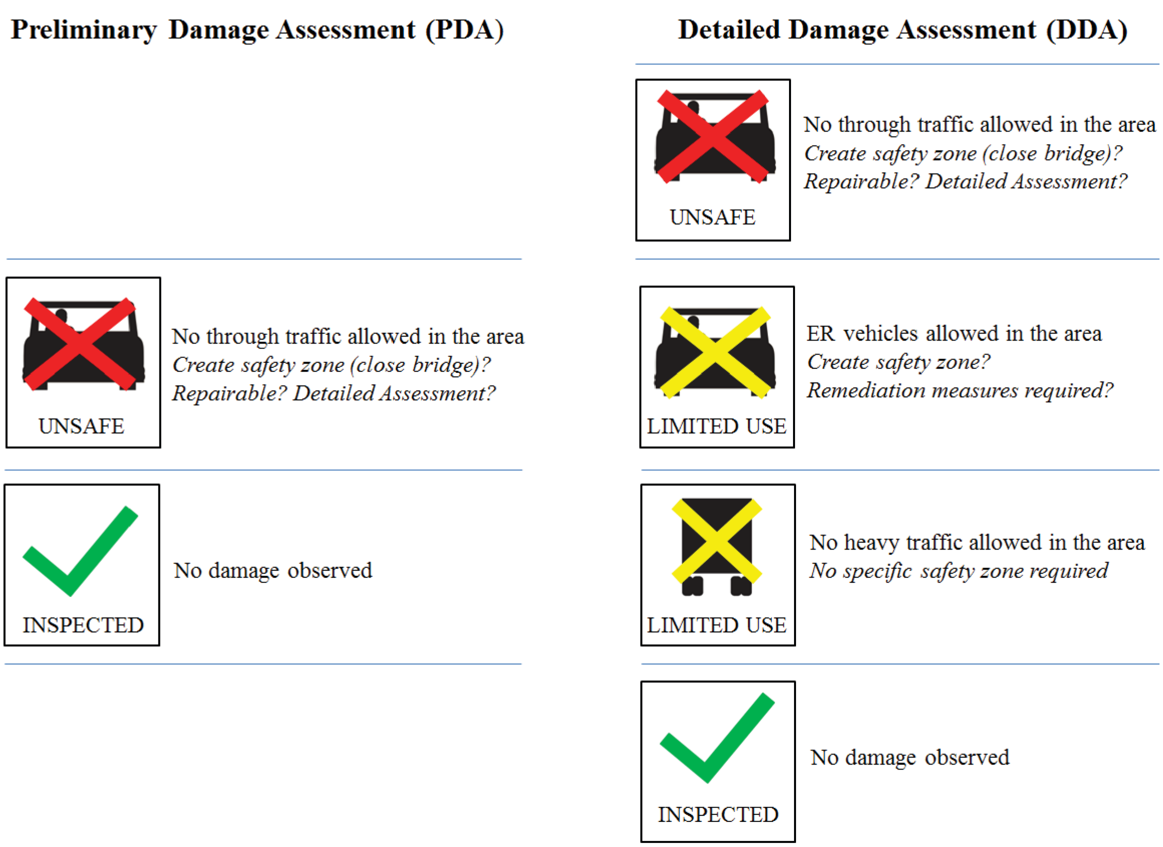


Figure 6-2. Marking codes for PDA (left) *and DDA* (right)*. These can be printed as decals to be placed on the placard shown in Figure 6-1.*

Table 6-1. 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.**

In addition to posting a highway structure, it may be necessary to designate restricted use of certain parts of the structure. These can be hazardous areas on or around the highway structure. 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.

There may be a need to change the coding and marking of a highway structure. This can result from several possible situations including the following:

- A DDA following an initial PDA
- An EI
- Reinspection to verify or correct an existing posting
- Reinspection after another emergency event
- Reinspection after temporary repairs have been made
- Reinspection after removal of finishes to expose concealed conditions

Any change in posting category must be done by an authorized representative of the agency in charge of that particular highway structure.

6.2 Element Damage Levels

Prior to coding and marking the overall structure, the PDARs should quickly assess the state of individual elements. This is useful information for load rating analyses at the DDA stage as well as for tracking the amount of damage for loss estimates.

This section provides definitions for the individual element ratings for each highway structure. It should be noted that these damage levels are separate from the final decision for overall coding and marking of the structure as either INSPECTED or UNSAFE. These damage levels are specific to basic structure elements and are used to provide information for repair, prioritization, and subsequent assessment procedures. These damage levels are marked in the assessment forms.

For each highway structure, a list of common elements is provided in *Volume 3: Coding and Marking Guidelines.* These elements should be reviewed independently and coded using Table 6-2. Each highway structure has different elements corresponding with damage level to be used for reference. When the condition of an element is not clear, it should be coded conservatively.

Upon coding the individual elements, an overall marking will be decided for the structure. When elements are coded as minor or moderate, the overall marking is less clear. A conservative judgment should be used when making the final marking decision. If a structural element (e.g., bridge columns, bearings, or wingwall; tunnel deck; overhead sign column support) receives a

Table 6-2. Element damage-level descriptions.

Damage Level	Description
None (Green)	The element and/or structure shows little to no signs of damage.
Minor (Yellow)	The element shows signs of cosmetic or non-structural damage that has little to no effect on the system integrity. Structure appears capable to carry traffic.
Moderate (Orange)	The element has experienced structural or geotechnical damage that may affect the system integrity.
Severe (Red)	The element is damaged where it cannot function properly. Structure may be in danger of collapse. If any element is marked as severe, the structure should be posted UNSAFE.

moderate damage-level rating, the structure should be marked as UNSAFE. If a non-structural element (e.g., bridge parapet, tunnel railing, and overhead sign catwalk) receives a moderate damage-level rating, the structure may be marked as INSPECTED, if there is no other structural damage, although precautions and cordoning off the affected areas should be made to ensure safety and to make sure users are aware that there is a safety hazard.

6.3 Assessment Form Integration

PDA forms provide information on the structural integrity of a highway structure following an emergency event. The information contained in these forms is especially useful for subsequent inspections such as DDA and EI. The "Damage Summary" section on the form is useful for providing an economic and monetary estimate on the damage to a structure. Although an estimate, this percentage can help managing engineers prioritize and plan for subsequent inspections and retrofits.

"Feature Description" ratings provide valuable information for DDA and EI evaluations. For example, if a structure is determined to have moderate damage for one element and no damage for the remaining elements, DDA and EI inspectors do not need to provide a detailed evaluation of the remaining elements. This is particularly useful for determining appropriate inspection technologies as managing engineers can better adjust the equipment needed.

CHAPTER 7

Coordination and Communication

7.1 Introduction

This chapter will discuss two of the fundamental elements of an ERP—coordination and communication. Although it is difficult to separate the two, coordination will be treated as primarily involving human resources, while communication will focus on the network itself.

A stress-tested, fail-safe communications network is critical to the coordination of an effective and rapid team response during an emergency event—one relies on the other. SHAs understand the importance of working with communications vendors, other agencies, and the general public so that they are prepared for as many scenarios as possible. Coordination and communication must be key components of an SHA's "First You Plan" (see Chapter 4) strategy.

A communications plan must consider worst-case scenarios where digital communications may not be available. In addition, the plan must address the need for redundancy. Each SHA will have to weigh the costs and benefits of investing in backup systems based on the likelihood and frequency of events. However, certain technologies and devices can be integrated into routine practice for better return on investment and ensuring that personnel are familiar with them. While future developments in communication technology are unknown, they are likely to lead to more reliability and choice, such as more cost-effective satellite communications.

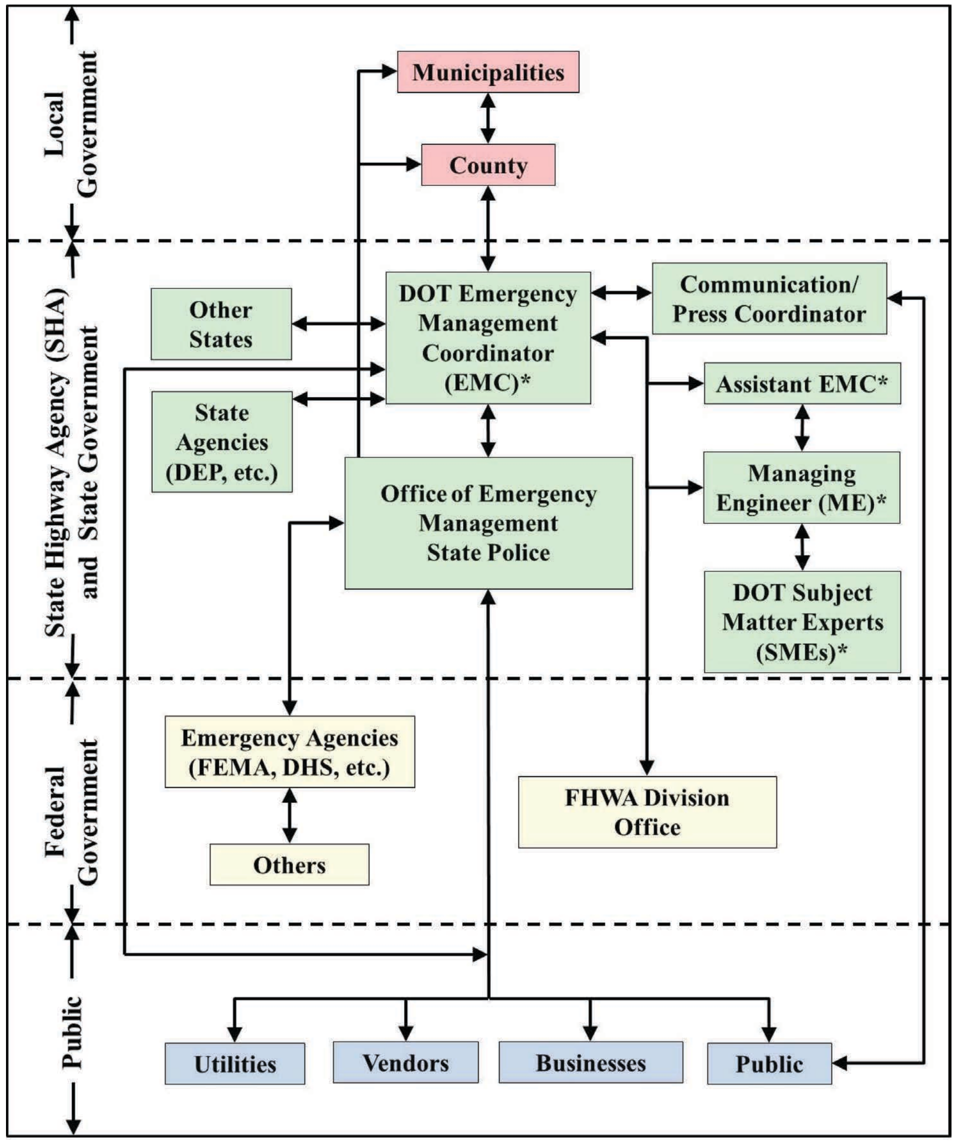
The planned coordination and supporting lines of communication should be well-established, understood, and practiced to the point where they are second nature to all involved parties prior to an emergency event. For the purposes of this chapter, four tiers of the coordination effort will be considered:

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

Figure 7-1 illustrates communication channels between local, state, federal, and public agencies. Much of the general emergency response coordination between these groups will be handled by the NIMS and Incident Command System (ICS). However, coordination specific to the assessing, coding, and marking of highway structures may require direct links between persons in each of the above groups.

7.2 Coordination

Coordinating an emergency response effort can potentially involve thousands of people, if the general public is included. As seen from recent events, this can be extremely challenging, often with people's lives at stake. It cannot be overstated, pre-event planning is essential to success.



* Refer to Interagency Communications
DEP = Department of Environmental Protection

Figure 7-1. Flowchart of proposed lines of communication.

From a human resources perspective, if the SHA has not already done so it will first need to establish an internal emergency management chain of command. It is essential that everyone who may become involved in the emergency response effort knows their role, what they are responsible for, and with whom/how they are to communicate. It may also be necessary to establish a backup person for each of the key roles. In many ways, coordination of the response effort should function similar to a military operation where the lines of communication and ranks of authority to make decisions are clearly known in advance. Figure 7-2 presents a recommended organizational structure for emergency structural assessments and communication within the SHA.

Table 7-1, along with the flowchart in Figure 7-1, is a summary of the proposed lines of communication and suggested protocols at each of the four tiers. Figure 7-2 also highlights

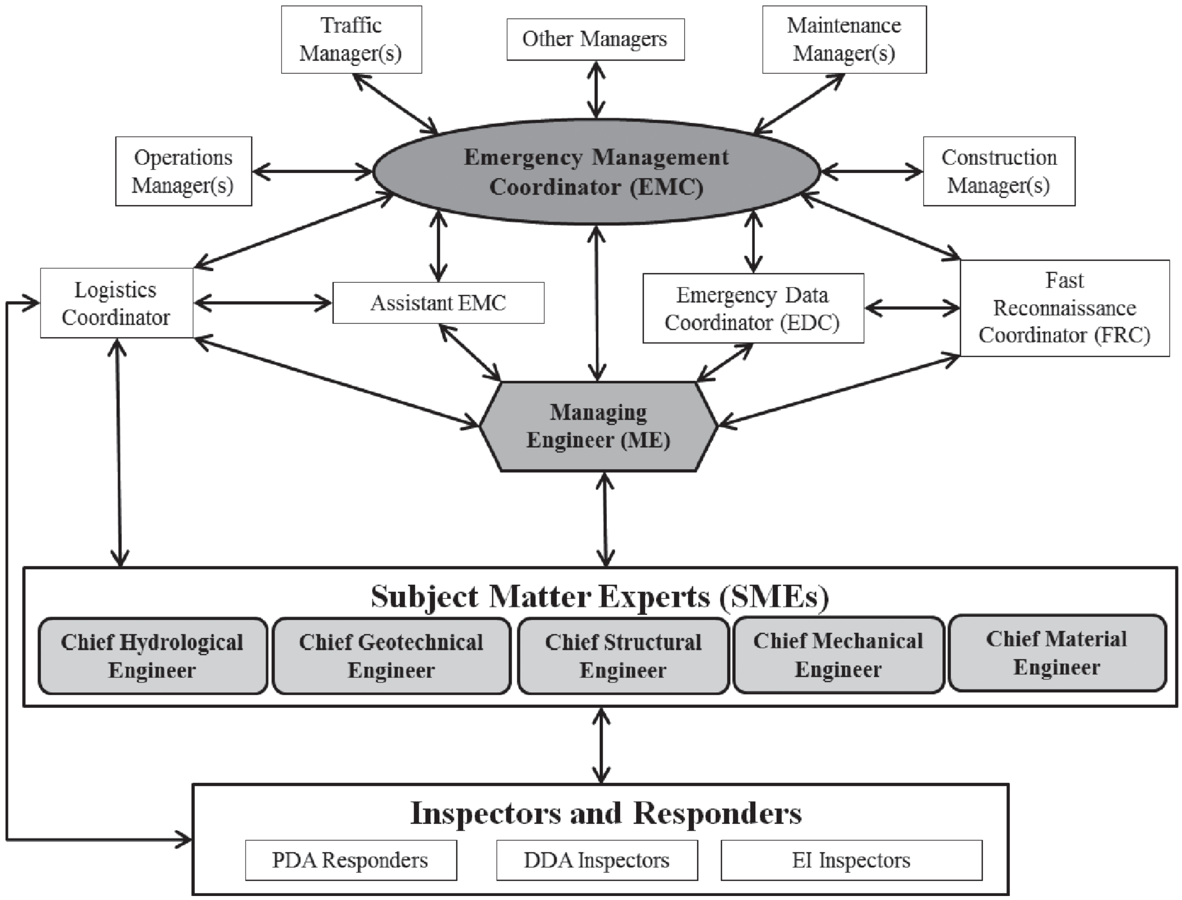


Figure 7-2. Interagency communication chain of command.

the proposed chain of command within the SHA. The remainder of this section provides key recommendations for coordination including general roles, development of response plans, FR coordination, and PDAR coordination.

7.2.1 General Response

The following leadership and logistical roles should be considered in the ERP:

1. A SHA EMC should be identified. Depending on the size of the state and the likely frequency of events, this could be a full-time position. The EMC will have the responsibility for developing an ERP that is best suited to the needs of their particular state and for the emergency event coordination.
2. Each state should identify an emergency data coordinator. This person coordinates all of the digital data, ensures its quality, and provides that data in a form that is most useful for the response. This person will establish and update data transfer protocols and ensure that these procedures are being followed.
3. Depending on the size of the state and the expected workload, it may make sense to assign a high-level individual as a logistics coordinator who coordinates logistic support (e.g., travel, housing, hospitalization) for the responders. These duties become particularly important if personnel are brought in from another region or state to assist.

Table 7-1. 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.

4. The SHA will need to establish a communication/press coordinator for coordinating with the public and press from an informational point of view. All other personnel should know what (if any) authority they have to communicate with the public.

7.2.2 Response Plans

When creating a response plan, the following elements of coordination need to be considered:

1. Response plans and procedures must be compatible with the NIMS and ICS and must be coordinated with other federal and state agencies such as FEMA and the DHS. This will avoid duplication of efforts and ensure that each group knows what its responsibilities are.
2. A streamlined procedure could be developed for smaller-scale or single-structure events. Utah DOT, for example, has developed a detailed ERP that designates minor and major response protocols (See Appendix E).

3. An emergency "call-in number" that connects to the emergency management center should be published as soon as possible after an event. The center should be staffed 24/7 with the appropriate number of people to handle the expected call volume. A website could also be used to communicate with the public and provide status updates.

7.2.3 Fast Reconnaissance

Coordination recommendations for FR include the following:

1. An FR coordinator should be identified to assemble the various sources of information and to report FR updates to the EMC, emergency data coordinator, and managing engineer. This individual organizes and monitors the FR efforts and reports the overall findings to help the managing engineer determine the appropriate response levels.
2. Immediately following an event, the ERP will be implemented beginning with a determination of the extent and severity of the damage. The state's traffic operations center will likely be the first group to receive reports from the traveling public. This information should be used to guide decision making about the level of mobilization and prioritization that needs to occur (e.g., response level). The ERP should anticipate as many of the possible scenarios as possible.
3. Given the rapid pace of technological change on the consumer electronics front, the SHA should continually assess how best to empower citizens with the ability to assist in the emergency management effort. Crowdsourcing could include public website portals and smart apps, or the use of hash tags for YouTube and Twitter, for example. The value and reliability of this crowdsourced data are likely to improve over time, but such data will probably not be considered a primary input to the assessment process for some time.

7.2.4 Preliminary Damage Assessment

The following procedures are recommended to improve coordination at the PDA stage:

1. Inspection routes should be prioritized, defined, and assigned to the proper personnel. Contingency plans with what-if scenarios should be presented and explained to increase the likelihood of success.
2. At the local level, each structure (or group of structures) and/or highway segment should be assigned to an individual beginning with someone at the district staff level who is most familiar with the assets and then continuing to roll up to the subject matter experts including the chief structural, geotechnical, hydrological, mechanical, and materials engineers, who in turn report to the managing engineer. The goal is to develop a sense of individual "ownership" for each structure/highway segment in the SHA inventory. These assignments should be made as part of the pre-event planning process.
3. Standard work packets should be developed for the PDAR teams that include *Volume 3: Coding and Marking Guidelines,* contact information, inspection route maps, information on the chain of command (see Figure 7-2), and protocols to properly communicate their findings. This information should be available digitally as well as in print form and reviewed periodically.
4. A list of office and personal cell phone numbers as well as email addresses for the key members of the emergency response team should be maintained up to date and distributed to all emergency personnel. If communication networks are not available, designated physical meeting locations should be established prior to the event as a backup. This same information should be kept up to date both in a digital network location and included in the *Coding and Marking Guidelines* along with maps and information concerning designated inspection routes and emergency communication network options.

5. A formal process of status reporting should be established to keep senior management informed with the most current information. These reports will describe affected areas, the impact of the event on traffic operations, identification of any closed or flagged highways/bridges, detailed accounts of damaged structures, inspected structures, and damage cost estimates, if available. As the response progresses, daily concise progress reports should be provided.

7.2.5 Lessons Learned and Review

A record of all meetings and decisions should be documented so that after the response is completed these materials can be reviewed and the lessons learned applied to future emergency planning and structural design activities. This will establish a spirit of continuous improvement regarding emergency response planning and operations as well as provide necessary data to support decisions made toward those improvements.

7.3 Communication

With the increasing use of mobile devices, including smartphones and smart tablets, it would greatly simplify the coordination efforts if the availability of these devices and supporting networks could be relied on during an emergency event. However, under extreme conditions, this is not likely to be the case with the current technology. Although the use of cell phones as the primary method of communication is being assumed, it is recommended that the communications plan include a worst-case scenario where digital communications networks are not available. It is also not uncommon to have large areas, particularly rural, without cell service in normal times. These areas should be identified and considered in the response plan in order to avoid any delays during assessment.

To address this issue, some providers are offering emergency government priority networks and/or portable emergency backup systems that should be considered as part of the pre-event planning. Table 7-2 provides a listing of communications networks and services that have been established to provide higher priority and backup to governments during emergency events. The pre-event training programs should include information on how and when to use these networks, as well as the procedures and protocols that should be followed. The emergency data coordinator or other IT professionals within or outside the SHA should be consulted so that proper communication networks are identified prior to occurrence of an event. As the reliability of the networks improves, likely through the use of satellite communications, the need for an off-network backup plan should be greatly reduced.

Table 7-2. Recommended emergency communication systems.

Service	Description	Benefits	Limitations	Web Link
Government Emergency Telecommunications Service (GETS)	GETS provides personnel priority access and prioritized processing in the local and long-distance segments of the landline networks.	• Increased probability of call completion • No special phones required • 90% call completion when call volume is eight times greater than normal network capacity	• Fees may apply • Does not preempt calls in progress • Used for landline networks	http://www.dhs.gov/government-emergency-telecommunications-service-gets
Wireless Priority Service (WPS)	WPS is a priority telecommunications service that improves the connection capabilities for authorized national security and emergency preparedness cell phone users.	• WPS calls receive priority over normal cellular calls • High probability of call completion	• Does not preempt calls in progress • Used for wireless telephone networks • Not supported by all carriers	https://www.dhs.gov/wireless-priority-service-wps
Voice-over-Internet Protocol (VoIP)	VoIP delivers voice communications over IP networks.	• Allows calls directly from a computer, a special VoIP phone, or a traditional phone connection to a special adapter	• Broadband (high speed internet) connection is required • A computer, adaptor, or specialized phone is required • Some VoIP services don't work during power outages	http://transition.fcc.gov/voip/
Mobile Communications Office Vehicle (MCOV)	MCOVs are multi-purpose vehicles that have been modified with work stations and satellite communications to provide voice and data connectivity to the FEMA network.	• Provides an office and communications platform capable of moving into a disaster on short notice • Enables FEMA to respond quickly and effectively • Flexible response	• Limited number of vehicles • Difficult for MCOV to navigate to disaster areas if the roads and/or structures are damaged	http://www.fema.gov/mobile-communications-office-vehicle
Mobile Emergency Response Support (MERS) Telecommunications	MERS telecommunications assets can temporarily establish or reestablish communications connectivity with the public telecommunications system or government telecommunications networks.	• High frequency (HF) to communicate with federal, state, and local emergency groups • Very high frequency (VHF) and ultra high frequency (UHF) for local radio communications	• Typically used for large-scale events when the local and state authorities do not have the appropriate resources	http://www.fema.gov/mobile-emergency-response-support-telecommunications
Sprint Emergency Response Team (ERT)	The Sprint ERT provides short-term wireless telecommunications equipment, infrastructure and operations support to federal, state and local government entities, public safety officials, law enforcement, military and private corporations.	• Rapid Deployment Solutions (RDS) • Satellite Cell on Light Trucks (SatCOLTS) • SatIP Fly-Away-Kits (FAKs) • Fixed-install antenna systems • Go-Kits • Short-term communication equipment rentals	• Fees may apply depending on resource needed	http://shop2.sprint.com/en/solutions/fixed_mobile_convergence/emergency_response_team.shtml
Tait Communications	Tait Communications is a multi-national radio communications company that develops voice and data radio technologies for fire and emergency response situations.	• Secure communications	Fees may apply depending on resource needed	http://www.taitradio.com/fire-emergency
Satellite communications technology	Communications satellites are artificial satellites sent to space for the purpose of telecommunications.	• Can be used when both telephones and land mobile radios are disconnected	• Lack of connection when responders lose line of sight	
Emergency Communications Network	Emergency Communications Network has built an Emergency Telephone Network database of resident contact information for use in critical situations.	• Includes warnings for flash floods, tornados, and tsunamis • Customizable based on private or public sectors		http://ecnetwork.com/
Telecommunications Service Priority (TSP) Program	TSP is a program that authorizes national security and emergency preparedness organizations to receive priority treatment for vital voice and data circuits or other telecommunications services.	• TSP restoration priorities must be requested and assigned before a service outage occurs	• Requires a subscription from Verizon	http://www.verizonenterprise.com/solutions/public_sector/federal/contracts/wits3/cust_care/telecom_security_fraud/nsep_programs/
SATRAD	SATRAD provides two-way, push-to-talk radio communications that enable public safety, first responders, and commercial users to extend radio communications.	• Talk groups can be configured to allow for interagency communications between local, regional, and national emergency response organizations • Can be installed in vehicles, provided as portable kits, or fix mounted	• Based on a flat rate per month	http://www.networkinv.com/technology/satrad-satellite-push-to-talk/

CHAPTER 8

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 chapter recommends assessment, coding, and marking technologies that are appropriate to identify, evaluate, map, or quantify damage on highway structures. Technology recommendations are associated with the suggested four assessment stages (FR, PDA, DDA, and EI) described in detail in Section 5.1. This discussion focuses on the FR and PDA stages.

These recommendations are grounded in the concepts of organizational (or institutional) maturity to classify different technologies for appropriate selection, which are described in the next section. Adequate training opportunities should be available and completed by PDARs.

Note that many types of FR do not require SHA personnel to work in the field and can be conducted from an office or remote platform. However, PDA, DDA, and EI are all field-based inspection activities. For this reason, it is recommended that PDARs be equipped with the appropriate safety equipment per each SHA's existing policies and regulations. "Best-practice" equipment lists compiled from several SHAs are introduced at the end of this chapter.

8.1 Classification of Recommended Technologies

Three classes are used to describe a technology's availability for practical use: (1) *commonly used technology,* (2) *available-for-use technology,* and (3) *emerging technology*. The recommended technologies are assigned to a class based on a thorough evaluation process that considered state-of-the-art literature and reported best practices. However, a technology's classification may change as it advances and market forces come into play.

Four criteria were used to classify the technologies: technological maturity; organizational maturity; applicability of the technology in terms of damage extent, level, types, and timelines; and evaluation of the technology in terms of many specific parameters (see *Volume 1: Research Overview* for further details). Technological maturity focuses on the readiness of the technology itself. Organizational maturity concerns an SHA's current comfort level with the technology and implies the general accessibility of resources or training materials within an SHA. Table 8-1 describes the technological maturity and organizational maturity of each class.

Table 8-1. Technology classification in terms of maturity metrics.

Availability	Technological Maturity	Organizational Maturity
Commonly used	• *Operational* as in the MCEER definition (Tralli 2000) • *Field proven* or TR9 as in the NASA definition (NASA 2012) • Herein interpreted as fully operational and practice proven in assessment practices • Examples include visual inspection aided by digital camera; smartphone, smart tablets, hand-held GPS device	• *Proficient* or *best practice* (AASHTO 2013) • In terms of training opportunities, (1) training opportunity is greatly available or (2) training opportunity is frequent and internal staff is capable of training others
Available for use	• Same as above however involving use of equipment that is specific (i.e., for a certain type of damage, structure, or emergency event) • Examples include survey equipment such as lidar, total station, or GPS	• Same as above however requiring special training for the specific equipment operation
Emerging	• Out of research and development phase and in *development* phase as in the Texas DOT definition (Jin et al. 2013) for emerging technology • Higher than the maturity of a technology that is scientifically feasible and tested in relevant environments as defined in NASA's TR6 definition • Herein interpreted as the emerging assessment technology that has been tested feasible and effective in limited disaster practice • Examples includes crowdsourcing and mobile technologies	• *Awakening* or *structured* (AASHTO 2013) • In terms of training opportunity, (1) no formal training materials are available or, (2) at most, some training materials are available

Source: Adapted from Jin et al. (2013), NASA (2012), Tralli (2000), and AASHTO (2013).

8.2 Technology Recommendations for Fast Reconnaissance

Efficient and effective FR quickly provides a global perspective of the geographic extents of the damaged region as well as the overall severity of the damage. It is based on rapid technology-based observation and/or reporting from both SHA personnel and the public. For example, the resulting GIS map products from a FR campaign 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).

8.2.1 Real-Time or Predictive Damage Estimation

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 the likely damage from the event:

- Predictive hazard forecast or loss estimation may be implemented for highway structures before a scenario event or in the immediate aftermath. For example, well-developed weather event forecast programs including NOAA's hurricane and storm surge simulation tools can be used to estimate the wind speed and the inundation depth geographically. For predictive loss estimation, the best of the practice would be to use the GIS-based ShakeCast (USGS 2014c) or FEMA's Hazus-MH (FEMA 2015) package to generate loss estimations and damage maps for common emergency event types (earthquakes, hurricanes, and flooding). It is noted that for estimation of highway structure damage, it requires prepared GIS-based inventory of structures, as described in Section 4.3.1.

Table 8-2. Predictive hazard forecast, loss estimation, and near-real-time hazard mapping technologies for use prior to 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

- Near-real-time hazard intensity mapping technologies can track the damage extent or monitor emergency event intensity immediately following the event, such as earthquakes and storm surges, which produces real mapping of products reflecting the intensity of the event. Today, many emergency events are monitored or tracked by modern radar or geodetic sensing networks. Examples are included in Table 8-2.
- Re-routing algorithms can consider damaged locations and provide recommendations for alternative travel on the highway network.
- Emerging technologies, especially for earthquakes, that combine intensity monitoring, loss estimation, aftershock forecast, and remote-sensing-based damage detection are being developed (e.g., the E-Decider project).

8.2.2 Data Gathering

Various FR technologies (Table 8-3) 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.

Public reporting through hotlines to the SHA's operation/management centers have been a mature practice adopted by many SHAs for obtaining emergency event and road/structure condition (including possible highway structure damage) information from the general public. Although the reporting may be point-based or sporadic, such information can be collected near real time as the public observes the damage in the first place.

The aerial survey method conducted by SHA personnel can provide a rapid visual assessment of emergency event extent and damage to critical highway structures. Geo-tagged digital cameras may be used for recording purposes during the flight and can be integrated with other ongoing damage mapping efforts. For smaller events, a vehicle can be driven without stopping in the affected area to determine the extent of the damage with a similar approach.

Data on the emergency extent and severity can be obtained from several other near-real-time or rapid technologies, including the following:

- Remotely sensed imaging: Data obtained from the USGS's Hazard Data Distribution System or the International Charter, both of which usually respond quickly for large-scale disasters

Table 8-3. 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 unmanned aerial systems) 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)

(e.g., from commercial satellites). These data provide rapid coverage of an event extent and damage potential.

- Civil Air Patrol, FEMA's community-based civilian pilot program: The Civil Air Patrol data (oblique imagery) for an emergency event have been widely used in the aftermath of Hurricane Sandy and Oklahoma's Moore tornado for rapid disaster assessment, and decision making.
- Several promising and emerging technologies: (1) small UAVs (or drones) used for small-scale event reconnaissance and (2) crowdsourcing through the use of specially designed smart apps (e.g., SpotOnResponse) for collecting near-real-time disaster data from the public or the professional communities.

These technologies usually produce data in the form of geospatially distributed data points, vector maps, oblique-view aerial images, or geo-tagged ground images. All of these data sources are suitable for immediate information fusion in GIS to support decision making and to create appropriate detour routes, minimizing traffic congestion problems that can lead to accidents or slow emergency event response efforts.

8.3 Technology Recommendations 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 PDARs' access to the structures can be generated.

Table 8-4. Recommended technologies for Preliminary Damage Assessment.

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)

Table 8-4 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.

Digital photographs can be useful to document the damage. Geo-positioning of field data (e.g., geo-tagging) can be collected using GPS devices and geo-tagging–capable imaging devices. The geo-tagged data can then be reported to the central repository and can be integrated with the GIS-based emergency databases previously developed during the FR stage. With this database support, the assessment in this stage may generate a preliminary percent damage estimate of the structure that can be used to develop overall preliminary damage estimates for the incident.

Note that a single, modern, mobile smart device (e.g., Android-, iOS-, or Microsoft Windows–based tablets and smartphones) usually integrates many of the essential tools for PDA including still and video cameras, GPS receiver, communication hardware, and maps with planned routes. The use of such devices with these basic functionalities, if possible, along with the pre-installed PDA app in one mobile device can greatly improve the efficiency of field inspection. When not available, visual inspection with manual completion of forms becomes the last resort (with the aid of manual devices, e.g., cameras, tapes, and notebooks).

In the case that communication networks are not available, a local copy of the central structural database can be pre-loaded on the smart device for offline access. Once a connection becomes available the device can automatically synchronize with headquarters. (Note that during emergency situations, it may be advantageous to disable or limit this syncing process if there is reduced bandwidth).

It is expected that in-situ decision making can be conducted and achieved for the object-of-interest, resulting in a damage rating and coding determination (Chapter 6) using these technologies. However, conclusive decisions may not be reached for some complex structures in a PDA, requiring more information through a DDA and more advanced technologies.

Along with the technologies, it is important to identify the information that is useful for PDARs and inspectors in the field and that which is important for the emergency operations center. Certain types of data can be pre-loaded on mobile devices (e.g., tablets). However, too much data can overwhelm the inspectors in the field; therefore, completeness and conciseness should be in balance. Note that IT staff at the SHAs may be needed to ensure that the mobile devices are up to date with software (e.g., a PDA smart app) and database versions, as applicable.

8.3.1 PDA Field Equipment

Structures within a transportation network pose uncertain dangers to inspection personnel especially after a major disastrous event. Technology equipment for inspection, basic and routine tools, protection, and safety gear and materials should be readily available in kits. These kits can be checked periodically during the emergency events planning and preparation (e.g., pre-event drills and training).

In this section, a comprehensive list of tools, gears, and materials (or "supplies" in general) for use in field inspection for the PDA stage is provided in Tables 8-5 and 8-6. This recommendation is based on the best practice developed by several SHAs (Appendix D).

Table 8-5. Item list for Preliminary Damage Assessment.

Prepackaged for Individual PDAR	Prepackaged for an Office	Quickly Available and Allocated
Assessment forms	Communication devices (radio transmitters)	Vehicles
Tool kit (includes inspection equipment, safety equipment, and personal supplies; see Table 8-6)	Charging equipment	Tablets (charged)
Placards	Backup supplies	Smartphones (charged)

Table 8-6. Recommended equipment list for Preliminary Damage Assessment.

Inspection Equipment		
Clipboard	Assessment forms	100′ measuring tape
Flashlight	Notepad	25′ pocket tape
Red paint marker and ribbon	Yellow paint marker and ribbon	Green paint marker and ribbon
Pens and pencils	Hammer	Keel/crayon
Binoculars	Cellular phone	Flagging tape
Duct tape	Portable ladder	Digital camera
Pliers	Micrometer	Wire brush
Chipping hammer	Pocket knife	Scraper
Traffic control equipment	Rope	Shovel
Boat*	Waders*	Underwater probe*
Electronic and Communication Equipment		
State or local maps	Laptop computer with charger	Copies of latest structure inspection files
Flash drives	Identification badges	Walkie-talkies or statewide radio
Satellite phone		
Safety Equipment		
Hard hat	Work boots	Safety vest
Ear plugs	Safety glasses	Rubber boots
Rain gear	Work gloves	Rubber gloves
Dust mask	Traffic cones	
Personal Supplies		
First aid kit	Drinking water	Sanitary items (e.g., toilet paper)
Food		

*Specialized PDAR teams for evaluating scour-critical structures

CHAPTER 9

Conclusions and Future Outlook

This assessment process manual provides guidance to help ensure a highly coordinated and efficient workflow for the assessing, coding, and marking of critical 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 assessment, coding, and marking process was subdivided into four stages: Fast Reconnaissance, Preliminary Damage Assessment, Detailed Damage Assessment, and Extended Investigation. This manual focused on the first two (FR and PDA). For the FR and PDA, element damage ratings and an overall marking classification were proposed. Roles of 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 combined with the National Bridge Inspection Standards. These procedures were developed to be compatible with the National Incident Management System and the 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 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 the response efforts and update the ERP 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 appropriate integration of technology. However, implementation of new technologies should consider organizational 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, everyday use, enabling the notion of smart inspection, marking, and coding 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, computer vision, and artificial intelligence. This may make it feasible to realize semi-automatic assessment of highway structures based on collected imagery. Eventually, autonomous PDA may be ultimately realized as human-based PDA is replaced in the long term with robotic, computer vision, and artificial intelligence technologies.

Finally, advanced GIS integration and interoperability technologies and infrastructure will become essential to support all assessment stages in the near-future given trends toward big data in transportation asset management, remote sensing, autonomous vehicles, mobile computing, and crowdsourcing technologies that support disaster response (Japan Science and Technology Agency/National Science Foundation 2014).

APPENDIX A

Highway Structure Background

This appendix presents basic information about common highway structures, including a description of the basic elements that would be evaluated in a PDA or DDA.

A.1 Bridges

Each bridge is composed of elements that function to provide resistance to loads (dead, live, wind, snow, earthquake, etc.). These element groups (Figure A-1) are described as follows:

- Superstructure—Primary, secondary, and tertiary load-bearing elements. These include slabs, beams, arches, parapet beams, and cantilevers.
- Substructure—Foundations, piers, abutments, columns, bearings, and cross-heads or bent-cap.
- Durability elements—Water proofing, drainage, surface finishes, and expansion joints.
- Safety elements—Guardrails, walkways, parapets, safety fences, and access gantries.
- Ancillary elements—Wing walls, embankments, lighting, and carriageway.

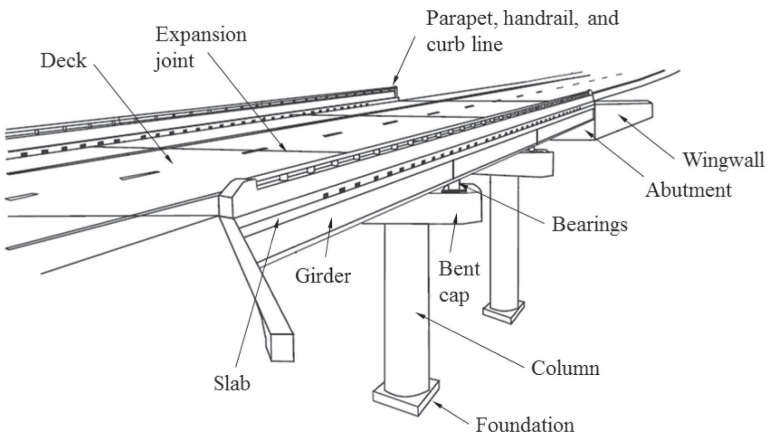
Emergency events are often variable in nature and can exert a combination of forces on the bridge requiring complex analyses. When these forces exceed the bridge's resisting capabilities, damage or failure can result. Capacity can be weakened by corrosion, fatigue, and other problems associated with long-term usage of a structure. Routine maintenance and regular inspections are critical to minimize these problems. Examples of bridge damage corresponding to specific types of emergency events are presented in *Volume 3: Coding and Marking Guidelines* and can be found in Ataei et al. (2010), Azadbakht (2013), Barbosa and Silva (2007), Brandt et al. (2011), FEMA (2001), FEMA (2005), Hoshikuma (2011), Huston and Bosch (1996), O'Connor (2010), Padgett et al. (2008), Pamuk et al. (2005), Parola et al. (1998), and Wright et al. (2013).

Scour is of particular concern to the structural safety of bridges because it can occur more frequently than emergency events such as earthquakes or hurricanes. It is the most common cause of highway bridge failures in the United States (Kattell and Eriksson 1998).

A.2 Tunnels

The four main shapes of highway tunnels are circular, rectangular, horseshoe, and oval/egg. Basic tunnel elements include the shape, material, tunnel lining, type, tunnel finish, and mechanical systems (electrical, ventilation, lighting).

Often, the most critical emergency event for tunnels is fire due to the confined space and localized impact. Fire results in thermal impacts on the tunnel, resulting in a potential loss of strength and stiffness as well as development of internal stresses, strain, and deformations



Source: Modified from Missouri DOT (2014).

Figure A-1. Typical modern bridge.

(Høj 2004). The ultimate consequence of fire is collapse from loss of structural support; however, localized damage and subsequent closing of the tunnel can cause significant transportation disruptions since there are few alternative routes. Additional examples of tunnel damages related to emergency events can be found in the following publications: Dowding and Rozan (1978), Maevski (2011), Scawthorn and Porter (2011), Wang et al. (2001), and Working Group 6 (1991).

A.3 Culverts

Culverts are designed for both hydraulic and structural loadings. The impacts of emergency events can increase the hydraulic loading and lead to serious failures or collapse of the culvert. Culverts are typically considered minor structures, but they are of great importance to adequate drainage and the integrity of the transportation network (Marek 2011).

A typical culvert is characterized by basic elements including the culvert material and cross-sectional shape, inlet, and wingwalls. Other elements include inverts, end protection, roadway, embankment, and footing. Culvert materials include concrete, corrugated aluminum, and corrugated steel. Typical culvert shapes are circular, arch, or rectangular in cross section.

The most common type of concrete culvert is the box culvert. Other types of culverts typically used in highway construction include corrugated metal pipe, thermoplastic pipe, reinforced concrete pipe, and reinforced concrete boxes (Youd and Beckman 1996).

Examples of culvert damages corresponding with the emergency events defined are available in publications such as Dissanayake (2005), Douglas et al. (2012), FEMA (2001, 2005), Parola et al. (1998), VicRoads (2011), and Youd and Beckman (1996).

A.4 Walls

For the purpose of this manual, walls are defined as any retaining, self-supported, or quay wall, regardless of height. In walls, the primary function is to act as a retaining structure for embankments, fill slopes, or natural slopes. They can be externally stabilized structures, internally stabilized structures, fill-type retaining walls, cut-type retaining walls, mechanically stabilized earth walls, or other geotechnical structures depending on the geotechnical mechanism used to resist lateral loads (Table A-1). Other walls of interest include quay walls and sea walls used to

Table A-1. Classification of wall structural types.

Fill-constructed walls (built from the bottom up)	
Externally stabilized	**Internally stabilized**
Rigid gravity walls • Masonry gravity walls (stone, concrete, brick) • Cast-in-place (CIP) concrete gravity walls Rigid semi-gravity walls • CIP concrete cantilever T-wall or L-wall (including counterforted walls and buttressed walls) Prefabricated modular gravity walls • Crib wall • Bin wall • Gabion wall Rockeries	Mechanically stabilized earth (MSE) walls • Segmental, pre-cast facing MSE wall • Prefabricated modular block facing • Flexible facing (geotextile, geogrid, or welded-wire facing) Reinforced soil slopes (RSS)

Cut-constructed walls (built from the top down)	
Externally stabilized	**Internally stabilized**
Non-gravity cantilevered (embedded) walls • Sheet-pile wall (steel, concrete, timber) • Soldier pile and lagging wall • Slurry (diaphragm) wall • Tangent/secant pile walls • Soil-mixed wall (SMW) Anchored walls* • Ground anchor (tieback) • Deadman anchor	In-situ reinforced walls • Soil-nailed wall • Root-pile wall • Insert pile wall

*Anchors are often used in combination with embedded walls of various types and may also be used in combination with semi-gravity cantilever walls.
Source: Sabatini et al. (1997).

block water from storms and tides. Note that these are often under the jurisdiction of agencies other than state highway agencies. Noise barriers are also common walls along highways in urban areas.

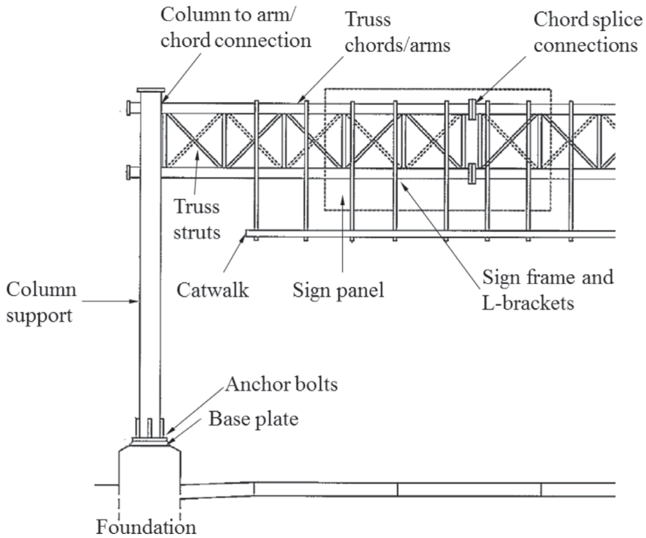
The main loading system on retaining walls is caused by the soil and hydrostatic pressure acting on the wall. Emergency events not only create unexpected loading on retaining walls, but they have the potential to disrupt and alter the characteristics of the soil or water pressure acting against the wall, generating critical forces and possible failure of the wall. Typical failure modes of these walls are sliding, overturning, bearing capacity, and shear failure.

Other walls such as quay walls and noise barriers can fail due to toppling from unanticipated lateral loading from hazards such as wind, earthquakes, or storm surge. For example, quay walls are often used to block storm surge and can fail due to hydrodynamic or hydrostatic forces on one side of the wall.

Several examples of wall damage, often from landslides and other emergency events are available in *Volume 3: Coding and Marking Guidelines* and literature such as Argyroudis et al. (2013), Brophy (2011), Dissanayake (2005), Ghobarah et al. (2006), Huang (2000), Koseki et al. (2012), and Pamuk et al. (2005).

A.5 Embankments

Embankments consist of placing large amounts of compacted soil to elevate the highway. Lightweight fill material such as geofoam can be used in place of soil. They often are connected to bridge approaches. The primary concern associated with highway embankments is the stability of the side slopes. Several publications address embankment slope instability and other damages associated with emergency events. The following is a partial list of some of those publications:



Source: Modified from Garlich and Thorkildsen (2005).

Figure A-2. Typical overhead sign schematic.

Adalier et al. (1998), Chen and Anderson (1987), Dissanayake (2005), Douglass and Krolak (2008), FEMA (2001), Hoshikuma (2011), Koseki et al. (2012), Parola et al. (1998), and Tokida (2012).

A.6 Overhead Signs

The basic elements/features on an overhead sign are the truss, connection, base connection, support, and foundation, as shown in Figure A-2. Overhead sign structures are initially designed to resist dead, live, ice, and wind loads. However, emergency events have the potential to increase the loading on the structure, possibly exceeding the allowable load and thus damaging the overhead sign. The unexpected failure of an overhead sign structure could result in increased traffic congestion, and accidents. Fatigue failures are most common and typically appear near welds, notches, holes, and material impurities (Kacin et al. 2010). Failures of foundation by flexure, shear, and torsion have also been observed. Examples of overhead sign damages corresponding with emergency events are available in FEMA (2005) and Garlich and Thorkildsen (2005).

APPENDIX B

Emergency Event Response Levels and Notifications

This appendix provides supplemental information to the response levels described in Chapter 5, including basic information about common hazard intensity levels and warning systems.

B.1 Earthquake

The moment magnitude scale is based on the total moment release of the earthquake represented on a base 10 logarithmic scale. Each particular earthquake has an associated moment magnitude that indicates the likely geographic scope of the earthquake. For example, the Northridge, California, earthquake in 1994 registered as a M6.7 earthquake.

Although moment magnitude provides an overall metric used to describe the earthquake moment magnitude, it does not provide an accurate representation of highway structure damage as this is dependent on the particular intensity of shaking at a given site. Hence, the modified Mercalli scale is more useful for determining the relative shaking intensity occurring at the site and the potential for damage to the structure.

The modified Mercalli scale uses the observations of people who experience the earthquake to estimate its intensity and is rated on a scale from I–XII. The scale quantifies the effects of an earthquake on the Earth's surface, humans, and man-made structures. It is a useful scale for determining the radius of intensity corresponding with a given earthquake. Although the Northridge earthquake registered as a M6.7 earthquake, the perceived shaking varied by location with some areas experiencing shaking intensities up to X near the epicenter.

The U.S. Geological Survey (USGS) developed ShakeMaps that provide near-real-time maps of ground motion and shaking intensity following significant earthquakes (USGS 2014d). These maps can be used for post-earthquake response and recovery, refining the prioritization of sites to perform PDA, public scientific information, and preparedness planning. For pre-earthquake planning, the USGS provides scenario earthquakes to simulate intensity measures. For post-earthquake use, the near-real-time ShakeMaps provide a geographical representation to the extent of the earthquake intensities (e.g., PGA, PGV, MMI). USGS also provides the Earthquake Notification Services (ENS) which sends automated notification emails when earthquakes happen in a particular area (see Figure B-1) (USGS 2014b). It is recommended that interested parties responsible for emergency operations and response under emergency events sign up to ENS on the USGS website (link provided in Section 2.2).

B.2 Tsunami

NOAA's Tsunami Warning Center (NTWC) provides current and up-to-date warnings for tsunamis around the world (NOAA/NWS 2014f). A sample tsunami warning is shown in Figure B-2. It is recommended to sign up for email and/or text notifications from the corresponding

6.7 Mw - CHINA-RUSSIA-NORTH KOREA BORDER

Preliminary Earthquake Report

Magnitude	6.7 Mw
Date-Time	18 Feb 2010 01:13:17 UTC 18 Feb 2010 10:13:17 near epicenter 17 Feb 2010 18:13:17 standard time in your timezone
Location	42.561N 130.835E
Depth	562 km
Distances	111 km (69 miles) NE (43 degrees) of Chongjin, North Korea 112 km (69 miles) ESE (107 degrees) of Yanji, Jilin, China 112 km (70 miles) SW (233 degrees) of Vladivostok, Russia 581 km (361 miles) NE (45 degrees) of PYONGYANG, North Korea
Location Uncertainty	Horizontal: ; Vertical
Parameters	Nph = 84; Dmin = 670.1 km; Rmss = ; Gp = 43° M-type = Mw; Version = 6
Event ID	US 2010swaf ****This event supersedes event AT00645559.*

For updates, maps, and technical information, see:
Event Page
or
USGS Earthquake Hazards Program

National Earthquake Information Center
U.S. Geological Survey
http://neic.usgs.gov/

Disclaimer

This email was sent to lisa@usgs.gov You requested mail for events between -90.0/90.0 latitude and 180.0/-180.0 longitude for M6.5 between 08:00 and 22:00 and M6.7 other times. To change your parameters or unsubscribe, go to: https://sslearthquake.usgs.gov/ens/

Source: USGS (2014a).

Figure B-1. Example of HTML earthquake report.

tsunami warning site based on geographical location. After an earthquake occurs, NOAA monitors the earthquake magnitude and determines the likelihood of a tsunami for given coastal locations. The amount of warning depends on the generation and propagation of the tsunami, but DOT managers can expect a warning of a few minutes to hours.

Pacific Ocean Message Definitions (NOAA/NWS 2014f):

- Tsunami Warning: A tsunami warning is issued by Pacific Tsunami Warning Center (PTWC) when a potential tsunami with significant widespread inundation is imminent or expected. Warnings alert the public that widespread, dangerous coastal flooding accompanied by powerful currents is possible and may continue for several hours after arrival of the initial wave. Warnings also alert emergency management officials to take action for the entire tsunami hazard zone.
- Tsunami Watch: A tsunami watch is issued to alert emergency management officials and the public of an event which may later impact the watch area. The watch area may be upgraded to a warning or canceled based on updated information and analysis.
- Tsunami Advisory: A tsunami advisory is issued due to the threat of a potential tsunami which may produce strong currents or waves. The threat may continue for several hours after the arrival of the initial wave. Widespread inundation is not expected for areas under an advisory.
- Tsunami Information: Tsunami information is used to inform that an earthquake has occurred and to advise regarding its potential to generate a tsunami. In most cases there is no threat of a destructive tsunami, and the information is used to prevent unnecessary evacuations as the earthquake may have been strongly felt in coastal areas. The information may, in appropriate situations, caution about the possibility of a destructive local tsunami for coasts located near an earthquake epicenter (usually within 100 km).

```
ZCZC
WEPA40 PHEB 081908
TSUPAC
TSUNAMI BULLETIN NUMBER 001
PACIFIC TSUNAMI WARNING CENTER/NOAA/NWS
ISSUED AT 1908Z 08 MAY 2007
```

Product header/valid time

```
THIS BULLETIN IS FOR AREAS WITHIN AND BORDERING THE PACIFIC
OCEAN AND ADJACENT SEAS...EXCEPT ALASKA...BRITISH COLUMBIA...
WASHINGTON...OREGON AND CALIFORNIA.
```

Headline

```
... A TSUNAMI WARNING AND WATCH ARE IN EFFECT ...

A TSUNAMI WARNING IS IN EFFECT FOR

 JAPAN / RUSSIA / MARCUS IS. / N. MARIANAS

A TSUNAMI WATCH IS IN EFFECT FOR

 GUAM / WAKE IS. / TAIWAN / YAP / PHILIPPINES / MARSHALL IS. /
 CHUUK / POHNPEI / BELAU / MIDWAY IS. / KOSRAE / INDONESIA /
 PAPUA NEW GUINEA / NAURU / KIRIBATI / JOHNSTON IS. / HAWAII

FOR ALL OTHER AREAS COVERED BY THIS BULLETIN, IT IS FOR
INFORMATION ONLY AT THIS TIME
```

Watch/Warning Section

```
THIS BULLETIN IS ISSUED AS ADVICE. ONLY NATIONAL OR LOCAL
GOVERNMENT AGENCIES HAVE THE AUTHORITY TO MAKE DECISIONS
REGARDING THE OFFICIAL STATUS IN EACH AREA AND ANY ACTIONS TO
BE TAKEN IN RESPONSE.
```

```
AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

 ORIGIN TIME -  1848Z 08 MAY 2007
 COORDINATES -  38.2 NORTH  143.1 EAST
 DEPTH       -   47 KM
 LOCATION    -  OFF EAST COAST OF HONSHU  JAPAN
 MAGNITUDE   -  8.2
```

Earthquake Parameters

```
EVALUATION

 IT IS NOT KNOWN THAT A TSUNAMI WAS GENERATED. THIS WARNING IS
 BASED ONLY ON THE EARTHQUAKE EVALUATION. AN EARTHQUAKE OF THIS
 SIZE HAS THE POTENTIAL TO GENERATE A DESTRUCTIVE TSUNAMI THAT CAN
 STRIKE COASTLINES NEAR THE EPICENTER WITHIN MINUTES AND MORE
 DISTANT COASTLINES WITHIN HOURS. AUTHORITIES SHOULD TAKE
 APPROPRIATE ACTION IN RESPONSE TO THIS POSSIBILITY. THIS CENTER
 WILL MONITOR SEA LEVEL DATA FROM GAUGES NEAR THE EARTHQUAKE TO
 DETERMINE IF A TSUNAMI WAS GENERATED AND ESTIMATE THE SEVERITY OF
 THE THREAT.
```

Tsunami Evaluation

Source: NOAA/NWS (2014f).

Figure B-2. Sample tsunami warning message.

ESTIMATED INITIAL TSUNAMI WAVE ARRIVAL TIMES. ACTUAL ARRIVAL TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE LARGEST. THE TIME BETWEEN SUCCESSIVE TSUNAMI WAVES CAN BE FIVE MINUTES TO ONE HOUR.

LOCATION		COORDINATES	ARRIVAL TIME
JAPAN	HACHINOHE	40.5N 142.0E	1932Z 08 MAY
	KUSHIRO	42.5N 144.5E	1933Z 08 MAY
	KATSUURA	35.1N 140.3E	1934Z 08 MAY
	SHIMIZU	32.5N 133.0E	2047Z 08 MAY
	OKINAWA	26.2N 127.8E	2148Z 08 MAY
RUSSIA	URUP IS	46.1N 150.5E	2016Z 08 MAY
	PETROPAVLOVSK K	53.2N 159.6E	2123Z 08 MAY
	SEVERO KURILSK	50.8N 156.1E	2130Z 08 MAY
	UST KAMCHATSK	56.1N 162.6E	2148Z 08 MAY
	MEDNNY IS	54.7N 167.4E	2150Z 08 MAY
MARCUS IS.	MARCUS IS.	24.3N 154.0E	2055Z 08 MAY
N. MARIANAS	SAIPAN	15.3N 145.8E	2159Z 08 MAY
GUAM	GUAM	13.4N 144.7E	2216Z 08 MAY
WAKE IS.	WAKE IS.	19.3N 166.6E	2223Z 08 MAY
TAIWAN	HUALIEN	24.0N 122.0E	2234Z 08 MAY
YAP	YAP IS.	9.5N 138.1E	2252Z 08 MAY
PHILIPPINES	PALANAN	17.1N 122.6E	2253Z 08 MAY
	LEGASPI	13.5N 124.0E	2312Z 08 MAY
	DAVAO	6.5N 126.0E	2339Z 08 MAY
MARSHALL IS.	ENIWETOK	11.4N 162.3E	2256Z 08 MAY
	KWAJALEIN	8.7N 167.7E	2341Z 08 MAY
	MAJURO	7.1N 171.4E	0010Z 09 MAY
CHUUK	CHUUK IS.	7.4N 151.8E	2258Z 08 MAY
POHNPEI	POHNPEI IS.	7.0N 158.2E	2312Z 08 MAY
BELAU	MALAKAL	7.3N 134.5E	2316Z 08 MAY
MIDWAY IS.	MIDWAY IS.	28.2N 177.4W	2325Z 08 MAY
KOSRAE	KOSRAE IS.	5.5N 163.0E	2340Z 08 MAY
INDONESIA	GEME	4.6N 126.8E	2346Z 08 MAY
	BEREBERE	2.5N 129.0E	2356Z 08 MAY
	PATANI	0.4N 128.8E	0022Z 09 MAY
	WARSA	0.6S 135.8E	0022Z 09 MAY
	MANOKWARI	1.0S 134.5E	0032Z 09 MAY
	JAYAPURA	2.4S 140.8E	0042Z 09 MAY
	SORONG	0.8S 131.1E	0045Z 09 MAY
PAPUA NEW GUINE	KAVIENG	2.5S 150.7E	0025Z 09 MAY
	MANUS IS.	2.0S 147.5E	0029Z 09 MAY
	VANIMO	2.6S 141.3E	0040Z 09 MAY
	RABAUL	4.2S 152.3E	0044Z 09 MAY
	WEWAK	3.5S 144.0E	0053Z 09 MAY
	AMUN	6.0S 154.7E	0109Z 09 MAY
	KIETA	6.1S 155.6E	0112Z 09 MAY
	MADANG	5.2S 145.8E	0112Z 09 MAY
	LAE	6.8S 147.0E	0150Z 09 MAY
	PORT MORESBY	9.3S 146.9E	0308Z 09 MAY
NAURU	NAURU	0.5S 166.9E	0043Z 09 MAY
KIRIBATI	TARAWA IS.	1.5N 173.0E	0056Z 09 MAY
	KANTON IS.	2.8S 171.7W	0224Z 09 MAY
	CHRISTMAS IS.	2.0N 157.5W	0337Z 09 MAY
	MALDEN IS.	3.9S 154.9W	0412Z 09 MAY
	FLINT IS.	11.4S 151.8W	0506Z 09 MAY
JOHNSTON IS.	JOHNSTON IS.	16.7N 169.5W	0059Z 09 MAY
HAWAII	NAWILIWILI	22.0N 159.4W	0153Z 09 MAY
	HONOLULU	21.3N 157.9W	0207Z 09 MAY
	HILO	20.0N 155.0W	0228Z 09 MAY

Estimated Tsunami Location and Arrival Times

Figure B-2. (Continued).

```
BULLETINS WILL BE ISSUED HOURLY OR SOONER IF CONDITIONS WARRANT.
THE TSUNAMI WARNING AND WATCH WILL REMAIN IN EFFECT UNTIL
FURTHER NOTICE.

THE JAPAN METEOROLOGICAL AGENCY MAY ALSO ISSUE TSUNAMI MESSAG
FOR THIS EVENT TO COUNTRIES IN THE NORTHWEST PACIFIC AND SOUTH
CHINA SEA REGION.  IN CASE OF CONFLICTING INFORMATION... THE
MORE CONSERVATIVE INFORMATION SHOULD BE USED FOR SAFETY.

THE WEST COAST/ALASKA TSUNAMI WARNING CENTER WILL ISSUE BULLETINS
FOR ALASKA - BRITISH COLUMBIA - WASHINGTON - OREGON - CALIFORNIA.
```

Bulletin Updates

```
NNNN
```

Figure B-2. (Continued).

- Tsunami Warning Cancellation: A cancellation indicates the end of a damaging tsunami threat. A cancellation is usually issued after an evaluation of sea level data confirms that a destructive tsunami will not impact the warned area. A cancellation will also be issued following a destructive tsunami when sea level readings indicate that the tsunami is below destructive levels and subsiding in most locations that can be monitored by PTWC.

B.3 Tornado and High Wind

High wind events are those with wind speeds ranging from 1 to 73 mph and are defined by the Beaufort scale (NOAA/NWS 2014d). The NWS offers high wind watch/warning and wind advisory notifications (NOAA/NWS 2014g).

High wind message definitions:

- High wind watch/warning: Issued when sustained winds of 40 mph or greater are possible/forecast for one hour or longer, or wind gusts of 58 mph or greater for any direction.
- Wind advisory: Issued when sustained winds of 31 to 39 mph are forecast for 3 hours or longer, or wind gusts of 46 to 57 mph for any direction.

Tornados are classified by the EF scale and have wind speeds from 65 to over 200 mph (NOAA/NWS 2014c). NWS and NOAA provide a tornado watch or warning advisory through the use of interactive weather maps (NOAA/NWS 2014g). Wireless Emergency Alerts are also used to send out notifications on the development and progress of tornados (NOAA/NWS 2014a). Figure B-3 shows a sample tornado warning.

Tornado message definitions:

- Tornado Watch: Conditions are conducive to the development of tornados in and close to the watch area.
- Tornado Warning: A tornado has been sighted by spotters or indicated on radar and is occurring or imminent in the warning area.

B.4 Hurricane and Strong Winds

Hurricanes and tropical storms are typically predicted ahead of contact with land by the National Hurricane Center. During this time, emergency management personnel should compile a list of all highway structures near the predicted areas of contact. For regions of land far away from the coastline, parameters such as wind speed and precipitation should be evaluated.

THE NATIONAL WEATHER SERVICE IN DES MOINES HAS ISSUES A

* TORNADO WARNING FOR...
NORTHERN GRUNDY COUNTY IN CENTRAL IOWA...
SOUTHEASTERN BUTLER COUNTY IN NORTH CENTRAL IOWA...
NORTHERN BLACK HAWK COUNTY IN NORTHEAST IOWA...
SOUTHERN BREMER COUNTY IN NORTHEAST IOWA...

Counties located in the warning

* UNTIL 550 PM CDT

Time the warning expires

* AT 459 PM CDT...A CONFIRMED LARGE AND EXTREMELY DANGEROUS TORNADO WAS LOCATED NEAR PARKERSBUR...OR 23 MILES NORTHWEST OF WATERLOO...AND MOVING EAST AT 33 MPH.

Information on how the tornado was detected and its location/movement

THIS IS A PARTICULARLY DANGEROUS SITUATION.

(Optional) – Only for powerful and life threatening

HAZARD...DAMAGING TORNADO AND GOLF BALL SIZE HAIL.

All threats in the storm

SOURCE...WEATHER SPOTTERS CONFIRMED TORANDO. A LARGE TORNADO HAS BEEN REPORTED EAST OF APLINGTON.

How the tornado was detected and any report details

IMPACT...YOU ARE IN A LIFE THREATENING SITUATION. MOBILE HOMES WILL BE DESTROYED. CONSIDERABLE DAMAGE TO HOMES...BUSINESSES AND VEHICLES IS LIKELY AND COMPLETE DESTRUCTION POSSIBLE. FLYING DEBRIS WILL BE DEADLY TO PEOPLE AND ANIMALS. EXPECT TREES TO BE UPROOTED OR SNAPPED.

The type of damage expected from the tornado

* LOCATIONS IMPACTED INCLUDE...
PARKERSBURG...NEW HARTFORD...
JANESVILLE...CEDAR FALLS...
WATERLOO AIRPORT...DENVER AND READLYN.

OR

THE TORNADO WILL BE NEAR...
PARKSERBURG BY 500 PM CDT...
NEW HARTFORD BY 510 PM CDT...
JANESVILLE AND CEDAR FALLS BY 525 PM CDT...
WATERLOO AIRPORT BY 530 PM CDT...
DENVER BY 540 PM CDT...
READLYN BY 550 PM CDT...

Cities or other major locations in the tornado's path – either a general list or with estimated arrival times

PRECAUTIONARY/PREPAREDNESS ACTIONS...

TO REPORT...A LARGE...EXTREMELY DANGEROUS AND POTENTIALLY DEADLY TORNADO IS ON THE GROUND. TO PROTECT YOUR LIFE...TAKE COVER NOW. MOVE TO AN INTERIOR ROOM ON THE LOWEST FLOOR OF A STURDY BUILDING. AVOID WINDOWS. IF IN A MOBILE HOME...A VEHICLE OR OUTDOORS...MOVE TO THE CLOSEST SUBSTANTIAL SHELTER AND PROTECT YOURSELF FROM FLYING DEBRIS.

Actions people should take if in the path of the tornado

Source: NOAA/NWS (2014g).

Figure B-3. Sample tornado warning message.

The National Hurricane Center provides information on forecast advisories, public advisories, discussions, and wind speed probabilities for corresponding hurricanes. These advisories include the location of hurricane, wind speeds, pressure, and storm surge heights (example shown in Figure B-4). Figure B-5 highlights an example of graphical output provided by NOAA during the development of hurricanes. This figure is useful for determining the geographical extent and intensity of hurricane wind events.

```
WTNT34 KNHC 120241
TCPAT4

BULLETIN
HURRICANE IKE ADVISORY NUMBER  44
NWS NATIONAL HURRICANE CENTER MIAMI FL   AL092008
1000 PM CDT THU SEP 11 2008
```

Product header/valid time

```
...IKE CONTINUES TO GROW IN SIZE BUT HAS NOT STRENGTHENED YET...
...HURRICANE WARNING ISSUED FOR NORTHWESTERN GULF COAST...
```

Headline

```
SUMMARY OF 1000 PM CDT...0300 UTC...INFORMATION
-----------------------------------------------
LOCATION...25.5N 88.4W
ABOUT 580 MI...930 KM ESE OF CORPUS CHRISTI TEXAS
ABOUT 470 MI...760 KM ESE OF GALVESTON TEXAS
MAXIMUM SUSTAINED WINDS...100 MPH...160 KM/H
PRESENT MOVEMENT...WNW OR 290 DEGREES AT 10 MPH...17 KM/H
MINIMUM CENTRAL PRESSURE...945 MB...27.91 INCHES
```

Summary Table Formatted for Parsing

```
WATCHES AND WARNINGS
--------------------
CHANGES WITH THIS ADVISORY...

A HURRICANE WARNING HAS BEEN ISSUED FROM MORGAN CITY LOUISIANA TO
BAFFIN BAY TEXAS.

A TROPICAL STORM WARNING HAS BEEN ISSUED FROM SOUTH OF BAFFIN BAY TO
PORT MANSFIELD TEXAS.

SUMMARY OF WATCHES AND WARNINGS IN EFFECT...

A HURRICANE WARNING IS IN EFFECT FOR...
* MORGAN CITY LOUISIANA TO BAFFIN BAY TEXAS

A TROPICAL STORM WARNING IS IN EFFECT FOR...
* EAST OF MORGAN CITY TO THE MISSISSIPPI-ALABAMA BORDER...INCLUDING
THE CITY OF NEW ORLEANS AND LAKE PONTCHARTRAIN

* SOUTH OF BAFFIN BAY TO PORT MANSFIELD

A HURRICANE WARNING MEANS THAT HURRICANE CONDITIONS ARE EXPECTED
SOMEWHERE WITHIN THE WARNING AREA.  A WARNING IS TYPICALLY ISSUED 36
HOURS BEFORE THE ANTICIPATED FIRST OCCURRENCE OF TROPICAL-STORM-FORCE
WINDS...CONDITIONS THAT MAKE OUTSIDE PREPARATIONS DIFFICULT OR
DANGEROUS.  PREPARATIONS TO PROTECT LIFE AND PROPERTY SHOULD BE
RUSHED TO COMPLETION.

A TROPICAL STORM WARNING MEANS THAT TROPICAL STORM CONDITIONS ARE
EXPECTED SOMEWHERE WITHIN THE WARNING AREA WITHIN THE NEXT 36 HOURS.
```

Watch/Warning Section with Changes Highlighted at the Top

```
FOR STORM INFORMATION SPECIFIC TO YOUR AREA...INCLUDING POSSIBLE
INLAND WATCHES AND WARNINGS...PLEASE MONITOR PRODUCTS ISSUED BY YOUR
LOCAL WEATHER OFFICE.
```

Figure B-4. Sample hurricane warning message.

DISCUSSION AND 48-HOUR OUTLOOK

Storm discussion and outlook for the next 48 hours

AT 1000 PM CDT...0300 UTC...THE CENTER OF HURRICANE IKE WAS LOCATED NEAR LATITUDE 25.5 NORTH...LONGITUDE 88.4 WEST. IKE IS MOVING TOWARD THE WEST-NORTHWEST NEAR 10 MPH...17 KM/H. A GENERAL WEST-NORTHWESTWARD MOTION IS EXPECTED OVER THE NEXT DAY OR SO...AND THE CENTER OF IKE SHOULD BE VERY NEAR THE COAST BY LATE FRIDAY.

Location and Movement

MAXIMUM SUSTAINED WINDS ARE NEAR 100 MPH...160 KM/H...WITH HIGHER GUSTS. IKE IS A CATEGORY TWO HURRICANE ON THE SAFFIR-SIMPSON SCALE. IKE IS FORECAST TO BECOME A MAJOR HURRICANE PRIOR TO REACHING THE COASTLINE.

Intensity

IKE REMAINS A VERY LARGE TROPICAL CYCLONE. HURRICANE FORCE WINDS EXTEND OUTWARD UP TO 115 MILES...185 KM...FROM THE CENTER...AND TROPICAL STORM FORCE WINDS EXTEND OUTWARD UP TO 275 MILES...445 KM.

Size

THE LATEST MINIMUM CENTRAL PRESSURE REPORTED BY A NOAA HURRICANE HUNTER AIRCRAFT WAS 945 MB...27.91 INCHES.

Pressure

HAZARDS AFFECTING LAND

Hazards Section

STORM SURGE...STORM SURGE WILL RAISE WATER LEVELS AS MUCH AS 10 TO 15 FT ABOVE GROUND LEVEL ALONG THE COAST WITHIN THE HURRICANE WARNING AREA...WITH LARGE AND DANGEROUS BATTERING WAVES...NEAR AND TO THE EAST OF WHERE THE CENTER OF IKE MAKES LANDFALL. STORM SURGE WILL RAISE WATER LEVELS AS MUCH AS 5 TO 7 FEET ABOVE GROUND LEVEL ALONG THE COAST WITHIN THE TROPICAL STORM WARNING AREA ALONG THE NORTHERN GULF COAST. THE SURGE COULD PENETRATE AS FAR INLAND AS ABOUT 10 MILES FROM THE SHORE WITH DEPTH GRADUALLY DECREASING AS THE WATER MOVES INLAND.

Storm surge

WIND...BECAUSE IKE IS A VERY LARGE TROPICAL CYCLONE...WEATHER WILL DETERIORATE ALONG THE COASTLINE LONG BEFORE THE CENTER REACHES THE COAST. HURRICANE CONDITIONS ARE EXPECTED TO REACH NORTHWESTERN GULF COAST WITHIN THE WARNING AREA FRIDAY AFTERNOON. WINDS ARE EXPECTED TO FIRST REACH TROPICAL STORM STRENGTH FRIDAY MORNING...MAKING OUTSIDE PREPARATIONS DIFFICULT OR DANGEROUS. PREPARATIONS TO PROTECT LIFE AND PROPERTY SHOULD BE RUSHED TO COMPLETION.

Wind

RAINFALL...IKE IS EXPECTED TO PRODUCE RAINFALL AMOUNTS OF 5 TO 10 INCHES ALONG THE CENTRAL AND UPPER TEXAS COAST AND OVER PORTIONS OF SOUTHWESTERN LOUISIANA...WITH ISOLATED MAXIMUM AMOUNTS OF 15 INCHES POSSIBLE. RAINFALL AMOUNTS OF 1 TO 2 INCHES ARE POSSIBLE OVER PORTIONS OF THE YUCATAN PENINSULA.

Rainfall

NEXT ADVISORY

NEXT INTERMEDIATE ADVISORY...100 AM CDT.
NEXT COMPLETE ADVISORY...400 AM CDT.

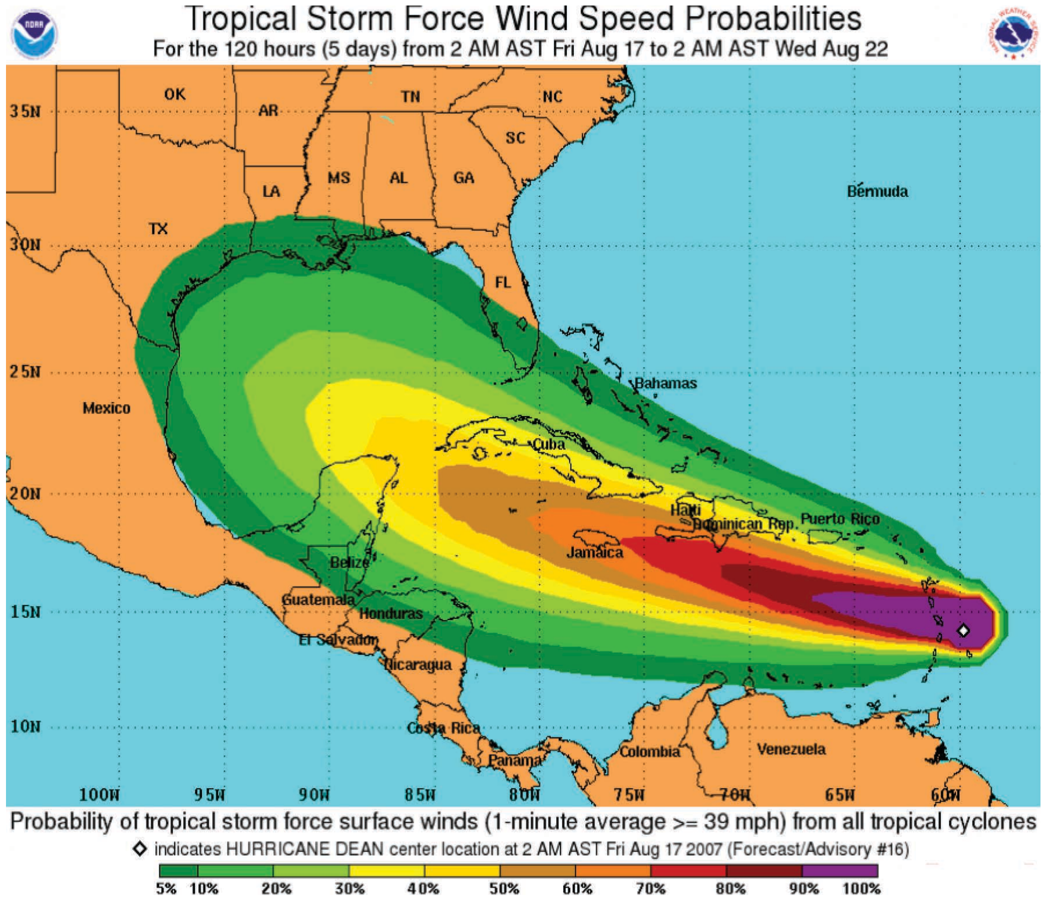
Product header/valid time

$$
FORECASTER FRANKLIN

NNNN

Source: NOAA/NWS (2014i).

Figure B-4. (Continued).



Source: NOAA/NWS (2014h).

Figure B-5. Tropical storm force wind speed probabilities.

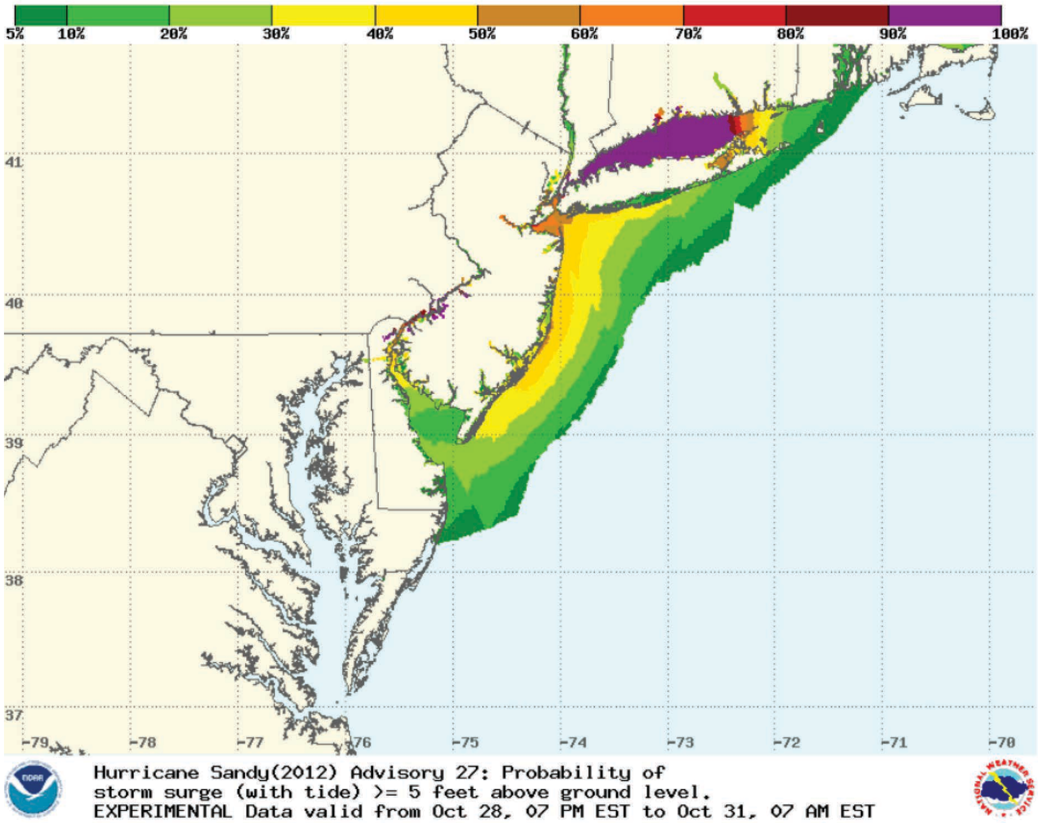
Forecast/advisories provide more detailed hurricane track and wind field information. Emergency management personnel should prepare inspection crews for areas with high wind levels. Once the hurricane subsides, crews should be dispatched to perform PDA inspections. It is recommended to inspect all highway structures within the hurricane warning area.

Hurricane warning definitions:

- Hurricane Watch: Hurricane conditions are possible within the specified area. Watches are issued 48 hours in advance of the anticipated onset of tropical-storm-force winds.
- Hurricane Warning: Hurricane conditions are expected within the specified area. Warnings are issued 36 hours in advance of the anticipated onset of tropical-storm-force winds.
- Extreme Wind Warning: Extreme sustained winds of a major hurricane (115 mph or greater), usually associated with the eyewall, are expected to begin within an hour.

B.5 Storm Surge

Storm surge is the rise of the water level above astronomical tide due to hurricanes. Storm surge often occurs over large areas of coastline and can damage highway structures due to repetitive wave loading. The storm surge heights used in Table 2-8 are consistent with hurricane categories from previous additions of the Saffir–Simpson hurricane scale. Storm surge heights



Source: NOAA/NWS (2014h).

Figure B-6. Tropical cyclone storm surge and tide probabilities.

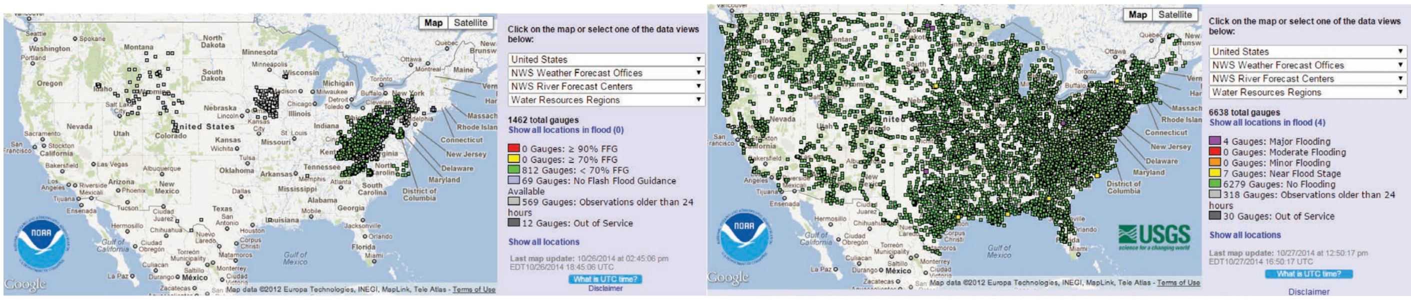
should be referenced with highway structure heights and in any cases where storm surge levels are expected to rise above the highway structure, evaluate using DDA. Figure B-6 highlights an example of graphical storm surge information provided by NOAA. These maps are useful for determining the geographical extent and intensity of storm surge water levels.

B.6 Flooding

Flooding is monitored by the National Weather Service (NWS) and can occur from precipitation, river flooding, and other weather events. Automated flood warning system (AFWS) maps are updated during the event of prolonged flooding at any location. AFWS maps highlight percent chance of flash flood guidance (FFG) (example shown in Figure B-7), river observations and forecasts, and precipitation estimates. FFG provides a general indication of the amount of rainfall necessary to cause small streams to overflow. River observations are used to determine the severity of flooding at rivers (minor, moderate, or major). Flooding can typically be estimated ahead of time due to rain and snow forecasts; however, the extent and magnitude can vary widely.

Flooding Definitions (NOAA/NWS 2014g):

- Near Flood Stage: Flooding begins to approach an established gage height for a given location. This gage height marks a water surface level that creates a hazard to lives, property, or commerce.



Source: (NOAA/NWS 2014g).

Figure B-7. Sample map of AFWS for precipitation observations **(left)** ***and river observations*** **(right).**

- Minor Flooding: Minimal or no property damage, but possibly some public threat or inconvenience. Floods with 5- to 10-year recurrence interval are assumed to cause minor flooding. A flood advisory is issued.
- Moderate Flooding: Some inundation of structures and roads near streams. Floods with 15- to 40-year recurrence interval are assumed to cause moderate flooding. A flood warning is issued.
- Major Flooding: Extensive inundation of structures and roads. Floods with 50- to 100-year recurrence interval are assumed to cause major flooding. A flood warning is issued.

APPENDIX C

Traffic Levels and Capacity

C.1 Introduction

In the context of emergency responses, knowledge of critical and vulnerable road links or highway structures is of great significance to reduce loss of life and increase the efficiency of transporting resources for recovery. Several state 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 consider the different ranges of traffic levels (i.e., AADT) and the composition of traffic (i.e., light vs. heavy vehicles). Public agencies should incorporate traffic levels when coding highway structures in emergency situations to prioritize and identify the most significant roadways when their remaining function has great impact on not only reducing the casualties, but also the performance of the transportation network in post-disaster emergency responses and recovery. Collaboration and coordination among agencies are required to consider the successful practices of other organizations that often respond to such emergencies.

This issue relies on capturing these segments before disaster, and trying to keep them functional during and after the event. Despite many efforts in this regard, there have been no universal standards about how to code and assess these highway facilities so far.

Emergency response relies on transportation network availability since emergency services need to reach the populated area and also the key resources such as hospitals and fire stations. Now, it is the responsibility of police departments to monitor traffic congestions and to provide solutions for effective traffic flow. The responsibility of local fire departments is to define the impact area and evacuate damaged structures (CH2M Hill 2012).

The objective of this appendix is to develop a process for incorporating different ranges of traffic levels into the assessment, coding, and marking of highway structures in emergency situations.

The rest of the appendix is organized into three sections. The section on assessment criteria reviews the different alternatives in the coding and marking processes. The section on traffic levels assessment proposes categories of traffic levels. The last section presents a procedure for implementation.

C.2 Assessment Criteria

Some of the procedures suggest using these criteria to process the assessment and coding:

- **Roadway functional classification:** It can be treated as the measure of the importance of the roadway in the local transportation network. It also mimics the ability of the facility to accommodate traffic. It is not a good criteria to replicate the exact features of the facility though.

- **Congestion:** Heavily congested roadways cannot accommodate rapid emergency response. At the same time, prediction of post-earthquake traffic patterns would be difficult. So, the "ability to control" highway structures use is of great significance rather than dedicating roadways to emergency services.
- **Emergency access routes:** Rather than routes that are typically important due to daily use, roadways near emergency facilities like hospitals and emergency response staging areas should be taken into consideration.
- **Interdependent lifelines:** Access to the critical utilities should be taken into consideration.
- **Capacity:** Under capacity criteria, the ability of the facility to accommodate freight vehicles, road width, and access control should be taken into consideration.
  - *Roadway width:* Number of lanes is mainly categorized in the following three levels.
    - Low: two or three lanes
    - Moderate: four or five lanes
    - High: six or more lanes
  - *Ability to control use:* This criterion is basically the ability to manage access through the segments. The number of controlled and uncontrolled intersections plays a critical role in access management. Normally, roads with high ability to control use perform better for commuting between populated areas.
    - Low: no access control
    - Moderate: limited access control (such as an expressway)
    - High: full access control (such as interstate freeway)
  - *Freight access:* The level of freight access to the road also plays an important role in emergency responses since it represents the ability of the goods and supplies to reach the populated areas.
    - Low: highly restricted to truck and oversized load traffic
    - Moderate: some restrictions for length or width
    - High: no freight restrictions

Figure C-1 shows how to take capacity criteria into consideration (CH2M Hill 2012). These criteria should be considered along with traffic data discussed in the next section.

C.3 Traffic Levels Assessment

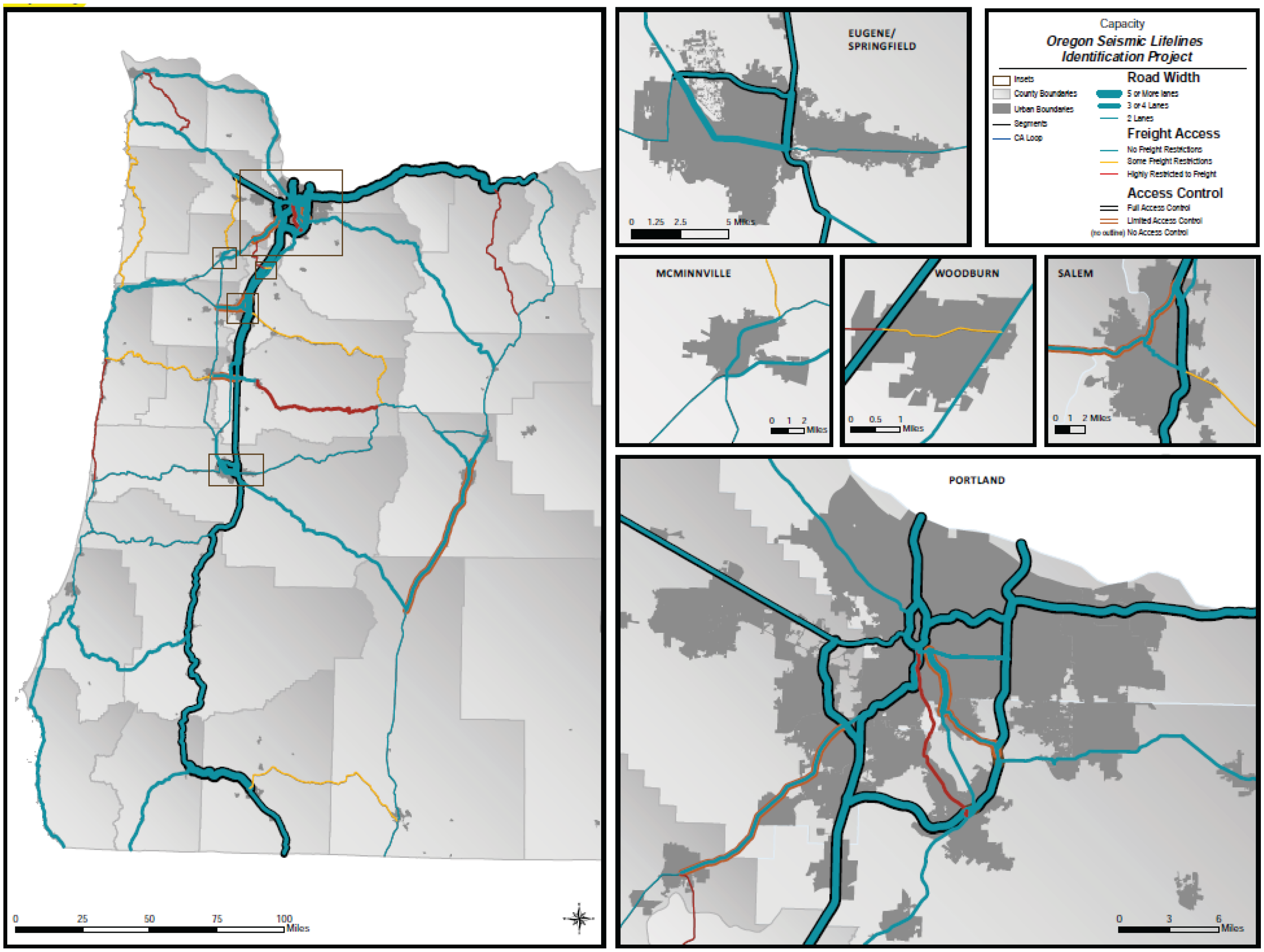
Table C-1 is extracted from the well-maintained *Code of Practice for Highway Inspection and Assessment,* and it seems that such network hierarchy can be used in the case of assessing and coding prior to traffic level analysis.

For general purposes like highway inspections, although it is pretty basic, some agencies categorize highways based on their estimated annual average daily traffic (AADT) level as follows (Rotherham Metropolitan Borough Council 2014):

- Traffic Level 1: greater than 80,000 vehicles/day (high)
- Traffic Level 2: 50,000 to 80,000 vehicles/day (moderately high)
- Traffic Level 3: 20,000 to 50,000 vehicles/day (medium)
- Traffic Level 4: less than 20,000 vehicles/day (low)

A more elaborate approach is to use average daily traffic (ADT) for the assessment. At the same time, considering the other criteria mentioned in the previous section and the facility types, ADT and AADT are the most-used measurements to address traffic stress levels on the facility:

- ADT: the total traffic volume during a given time period, ranging from 2 to 364 consecutive days, divided by the number of days in that time period, and expressed in vehicles per day
- AADT: average daily traffic on a roadway link for all days of the week during a period of one year, expressed in vehicles per day



Source: CH2M Hill (2012).

Figure C-1. Assessment criteria.

Since the AADT is more stable and is widely used for planning purposes, in this work the research team suggests using AADT for coding a traffic level on a highway structure. In addition, availability of the data justified the use of AADT since most of the DOTs collect and spread these data. It is also worth mentioning that these data are collected based on different vehicle classifications. In Oregon, the data are collected through the Transportation Systems Monitoring Unit which has the mission to formulate a system to collect and process traffic-related data on Oregon's highways. The raw data collected involve traffic volumes, manual counts, and vehicle class. Based on those, flow maps and other information can be drawn (Oregon DOT 2015).

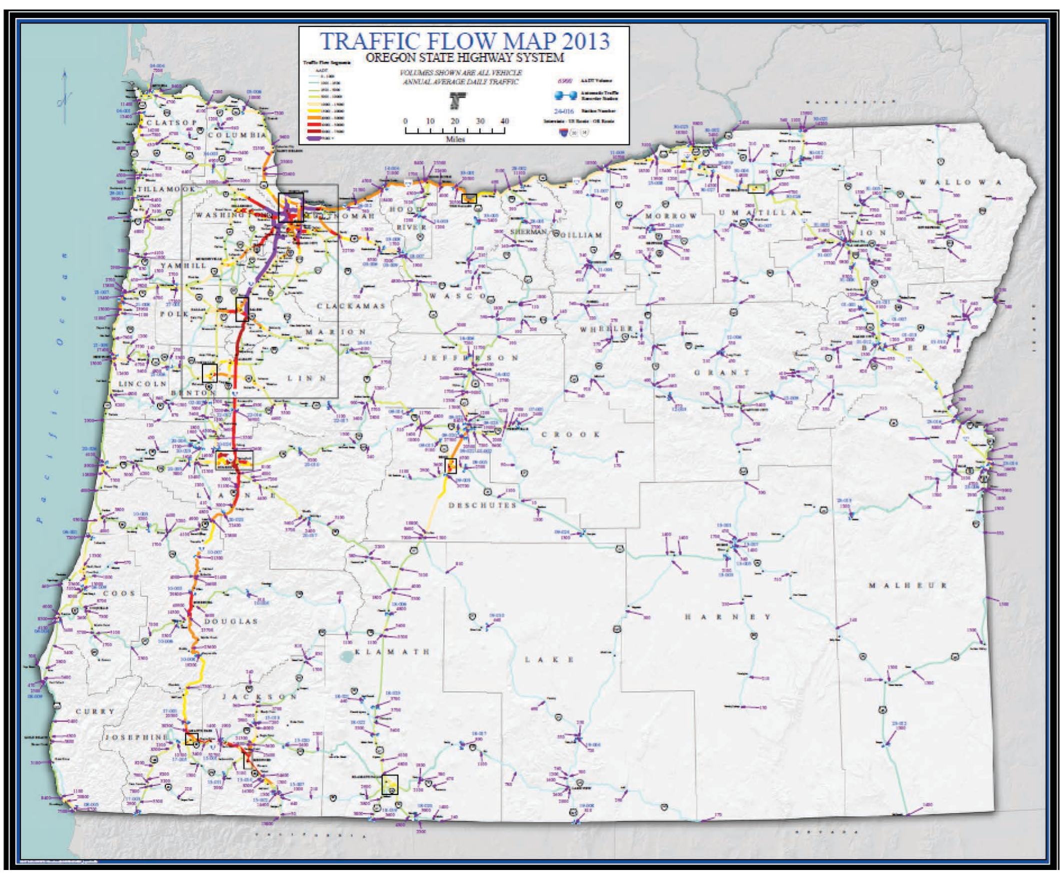
The color-coded maps in Figures C-2, C-3, and C-4 were downloaded directly from the Oregon DOT website. For the purpose of this study, incorporation of these maps, and the previous one, can lead to a general consensus on the standard of assessing and coding the highway structures.

Table C-2 shows the categories recommended by the Oregon DOT to analyze traffic flow.

Table C-1. Transportation network hierarchy.

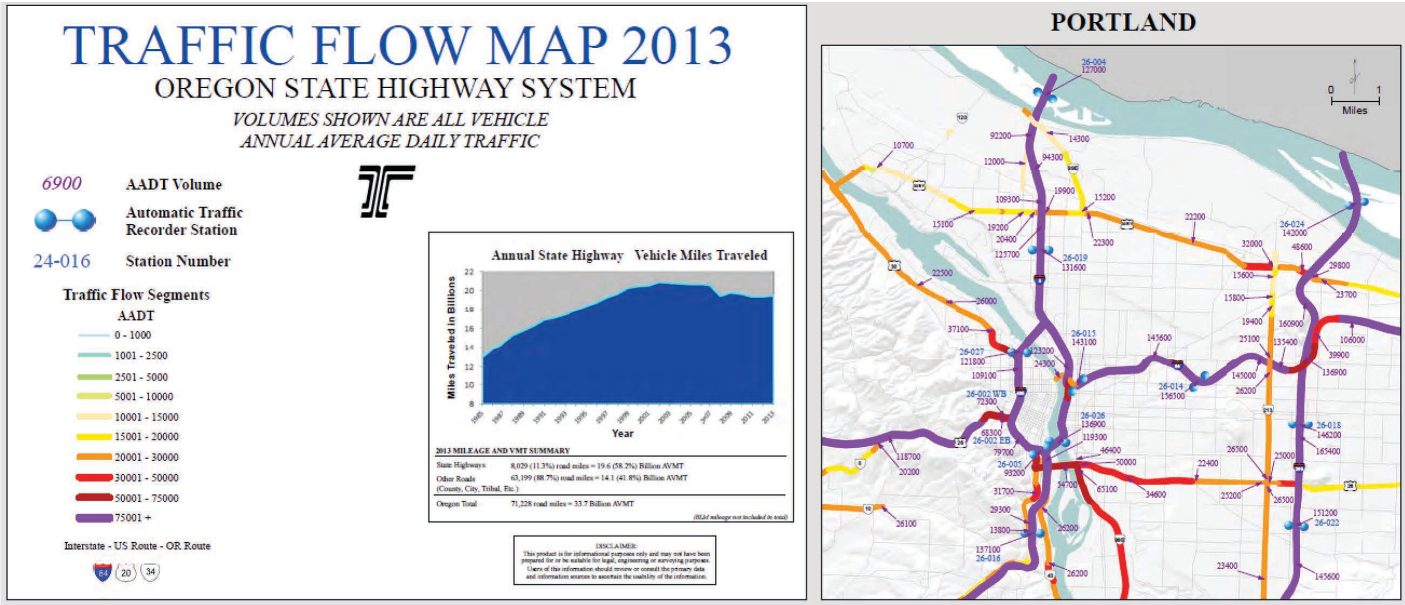
Facility Type	General Description of Type of Road	Detailed Description
Motorway	Limited access motorway regulations apply	Routes for fast-moving long-distance traffic. Fully grade separated and restrictions on use.
Strategic Route	Trunk and some principal 'A' roads between primary destinations	Routes for fast-moving long-distance traffic with little frontage access or pedestrian traffic. Speed limits are usually in excess of 40 mph and there are few junctions. Pedestrian crossings are either segregated or controlled and parked vehicles are generally prohibited.
Main Distributor	Major urban network and inter-primary links; short- to medium-distance traffic	Routes between strategic routes and that link urban centers to the strategic network with limited frontage access. In urban areas, speed limits are usually 40 mph or less, parking is restricted at peak times and there are positive measures for pedestrian safety.
Secondary Distributor	Classified road (B and C class) and unclassified urban bus route carrying local traffic with frontage access and frequent junctions	In rural areas, these roads link the larger villages and heavy goods vehicle generators to the strategic and main distributor network. In built-up areas, these roads have 30 mph speed limits and very high levels of pedestrian activity with some crossings. On-street parking is generally unrestricted except for safety reasons.
Link Road	Roads linking between the main and secondary distributor network with frontage access and frequent junctions	In rural areas, these roads link the smaller villages to the distributor roads. They are of varying width and not always capable of carrying two-way traffic. In urban areas, they are residential or industrial inter-connecting roads with 30 mph speed limits, random pedestrian movements, and uncontrolled parking.
Local Access Road	Roads serving limited numbers of properties carrying only access traffic	In rural areas, these roads serve small settlements and provide access to individual properties and land. They are often only single lane width and unsuitable for heavy goods vehicles. In urban areas they are often residential loop roads.

Source: Rotherham Metropolitan Borough Council (2014).



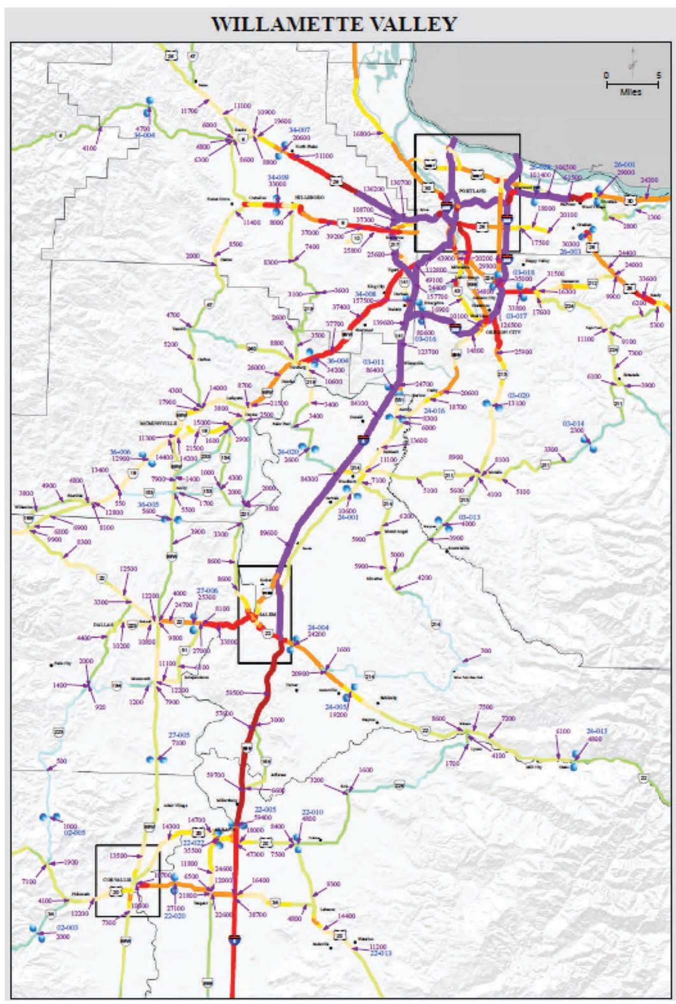
Source: Oregon DOT (2015).

Figure C-2. Traffic flow map – Oregon 2013.



Source: Oregon DOT (2015).

Figure C-3. Traffic flow map – Oregon 2013, Portland area.



Source: Oregon DOT (2015).

Figure C-4. Traffic flow map – Oregon 2013, Willamette Valley area.

Table C-2. Traffic levels.

Levels	AADT Range		Color
1	0	1000	
2	1001	2500	
3	2501	5000	
4	5001	10000	
5	10001	15000	
6	15001	20000	
7	20001	30000	
8	30001	50000	
9	50001	75000	
10	75001	+	

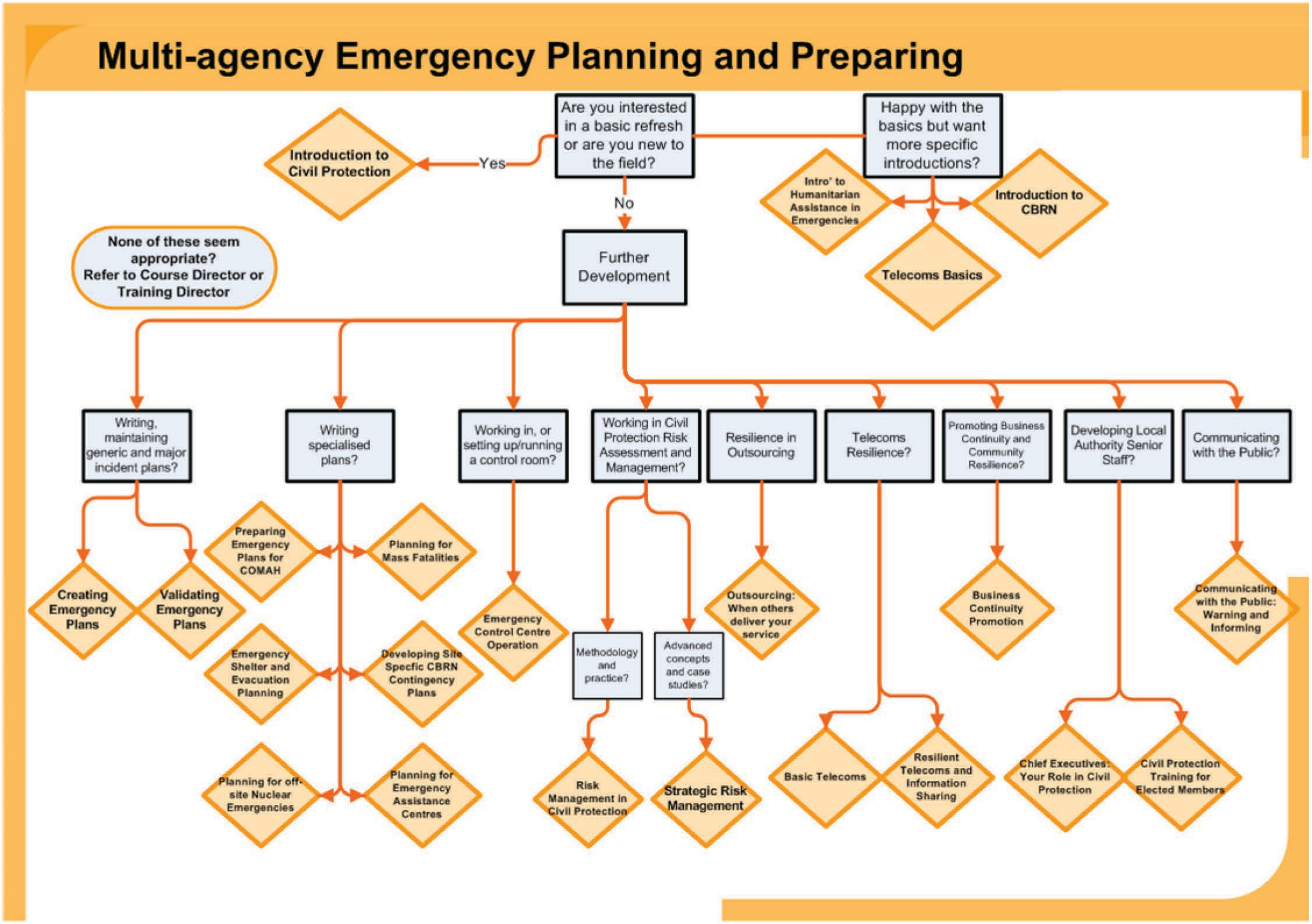
Source: Oregon DOT (2015).

C.4 Procedure

In sum, the assessment, coding, and marking of highway structures should consider a combination of the criteria concurrently; however, it is difficult to consider all the important criteria mentioned in this document. As a rule of thumb, if only the ranges of traffic levels are considered, the following procedure is recommended:

1. Establish a multi-agency coordination mechanism (e.g., Figure C-5) to respond to emergency situations that includes state DOT, emergency management department, and city or local jurisdiction metropolitan planning organizations
2. Identify highways, strategic routes, and primary distributors based on their attributes and the functional classification based FHWA criteria
3. Integrate the lifeline routes and prioritizations into the consideration if this is available
4. Identify critical organizations such as hospitals or fire stations and vulnerable transportation network components (i.e., bridges and overpasses)
5. Identify traffic levels (i.e., AADT) typically as traffic flow maps represented by AADT collected by automatic traffic recorder by state DOTs
6. Determine the priority of assessing, coding and marking highway structures in emergency situations.

In terms of marking post-disaster damaged highways facilities, one of the approaches implemented by the U.S. DOT is that, in some emergency situations, vehicles driving on specific segments are required to have special permits (EPC 2015). Some other agencies implement some restrictions on oversize or overweight trucks and freight vehicles (FHWA 2015b). In some other cases portable changeable message signs are towed to any place they are needed. They can easily be used in emergency situations to convey the appropriate message to achieve traffic management purposes (Texas DOT 2006).



Source: EPC (2015).

Figure C-5. Example of a multi-agency emergency planning and preparedness diagram.

APPENDIX D

Equipment List

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
Clothing and Safety	1	Hardhat		E	E			
	2	Safety vest		E	E			
	3	First aid kit	Extra large		E			
	4	Fire extinguisher			R			
	5	Ear plugs		E	A			
	6	Boots		E	A			
	7	Safety glasses/goggles		E	A			
	8	Gloves, leather		E	A			
	9	Climbing harness						
	10	Ropes, lanyards, safety lines						
	11	Life vests (over water)						
	12	Plastic gloves, disposable		A	E			
	13	Dust masks, disposable		A	E			
	14	Insect and tick repellent						
	15	Walkie-talkies			A	E		Useful in urban areas
	16	Air horn warning device			E			
	17	Power ventilation equipment				A		
	18	Miner's light on hard hat			R			
	19	Coveralls, disposable		E	A			For hazardous materials
	20	Disposable cartridge mask		R	A	E		
	21	Gas mask				S		
	22	Gas detector				S		For use in long culverts
	23	Breathing apparatus				S		
	24	Mace or animal repellent			E			Emergency use, animals
	25	Fresh water		E				
	26	Watch						
	27	Hip boots						

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
Inspection Equipment	1	Tool belt		E				
	2	Geologist pick		E	E			
	3	Cold chisel			E			
	4	Center punch			E			
	5	Scratch awl		R	E			
	6	Flashlight and batteries		E	E			
	7	Extra batteries and bulbs			E			
	8	Magnifying glass	5x or 10x		E			Built-in light recommended
	9	Binoculars	7x35		E			Or 7x50
	10	Mirror on swivel head			E			
	11	Extensive arm for mirror			E			
	12	Graphite-based penetrating oil			A			
	13	Dye penetrant kit			R	E		
	14	Drill, rechargeable, 14.0 volts	3/8″		E			With carrying case
	15	Drill bits, various	1/8″ – 1/2″		E			
	16	Grinding discs, various			E			
	17	Grinder, electric, 4" angle			R			With carrying case
	18	Spray paint			E			
	19	Heavy duty pliers			E			
	20	Heavy duty adjustable wrench			E			
	21	Screw drivers, assorted			E			
	22	Hammer, ballpeen	40 oz		E			
	23	Hammer, deadblow			E			
	24	Hand sledge	5 lb		E			
	25	Clamps, assorted			E			
	26	Crow bar	Large		E			
	27	Probing poles			E			
	28	Chain drag			A	E		
	29	Pachometer			A	A	E	

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
Inspection Equipment	30	Swiss hammer			A	A		
	31	Paint film gauge			R	E		
	32	Hilit hammer drill, with accessories			A	R	E	
	33	Increment borer, with brace				E		
	34	Boring bits	1/4″ and 3/8″			E		
	35	Treated wooden plugs	1/4″ and 3/8″			E		
	36	Drill, electric variable speed	1/2″			A	E	With magnetic base
	37	Drill bits, various	1/4″ - 1″			A	E	
	38	Electric hand-held grinder	4"		E	E		With case
	39	Power brush			E	E		
	40	Wire wheels			E	E		
	41	Electric pencil grinder			E	E		
	42	Grinding stones			E	E		
	43	Heavy duty extension cords	15 A, 100'		E			
	44	Flood lights				E		
	45	Trouble lights			E			
	46	Generator, light duty			R		E	Gas powered
	47	Rod level			A			
	48	Heavy duty bolt cutters			E			
	49	Torque wrench (2)	Small, large		E			For 3/4″, 7/8″ and 1" bolts
	50	Socket set	1/2″ drive		E			
	51	Weed cutter, gas powered				A		
	52	Digging bar			E			
	53	Core sampler, deck	4″ dia.			A	E	
	54	Core sampler, horizontal	2″ dia.			A	E	
	55	Magnet	Small		E			
	56	Lock level			E			With right angle deflector
	57	Red, yellow, and green paint marker			R			

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
Inspection Equipment	58	Pocket knife						
	59	Wire cutters						
	60	Portable ladder						
	61	Duct tape						
	62	Wrench						
	63	Micrometer						
Measuring Tools	1	Tape, metal, power return	25′	R	E			
	2	Folding rule	6″	E	A			
	3	Pocket scale	6″	E	E			
	4	Measuring tape, fiberglass	100′		E			
	5	Transit or level			A			
	6	Other surveying equipment			A			
	7	Telescoping measuring rod	25′		E			
	8	Plumb bob (2)			E			
	9	String level (2)			E			
	10	Line level			E			
	11	Torpedo level			E			
	12	Carpenter level	4′ or 6′		E			
	13	Straight edge	6′		E			
	14	Carpenter square			E			
	15	Combination square			E			
	16	Feeler gauges			E			
	17	Caliper (inside)	Small and large			A		
	18	Caliper (outside)	Small and large		E			
	19	Optical crack gauge		R	E			With contrasting backgrounds
	20	Ultrasonic thickness gauge			E	E		D-Meter
	21	Protractor			E			Or tiltmeter
	22	Magnetic particle equipment				A		Available through BOC

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
Measuring Tools	23	Dial gauges with bases (3)			A	E		
	24	pH text kit				A	R	
	25	Air thermometer		E				
	26	Contact thermometer		E	E			
	27	Sounding weight		E	E			With graduated cord
	28	Radiographic equipment				A		
	29	Electronic distance gage		R				For vertical clearances
	30	Compass						
	31	6-foot, 4-foot, and 2-foot level				A		
Access Equipment	1	Boat, boat motor, oars, anchor			A	E		Rental ok
	2	Life vests			A	E		Rental ok
	3	Boat trailer			A	R		Rental ok
	4	Ladder, step	8′		R	E		
	5	Extension ladder	8′–12′		E			Medium duty, minimum
	6	Extension ladder	24′–36′		R	E		Medium duty, minimum
	7	Ladder leveling legs			E			
	8	Set of tie down straps			E			
	9	Stand off ladder attachment			A			
	10	Aluminum extension plank	12″ x 20′		A			
	11	Personal lift vehicle	Small		A	A	E	Rental ok
	12	Scaffolds, travelers or cabling			A		S	
	13	Ladder scaffolding brackets			A		S	
	14	Skylock offset bracket			A		S	
	15	Stirrups			A		S	
	16	Parapet clam			A		S	
	17	Rope grabs, anti-fall device			A			
	18	Rope ladder			A			

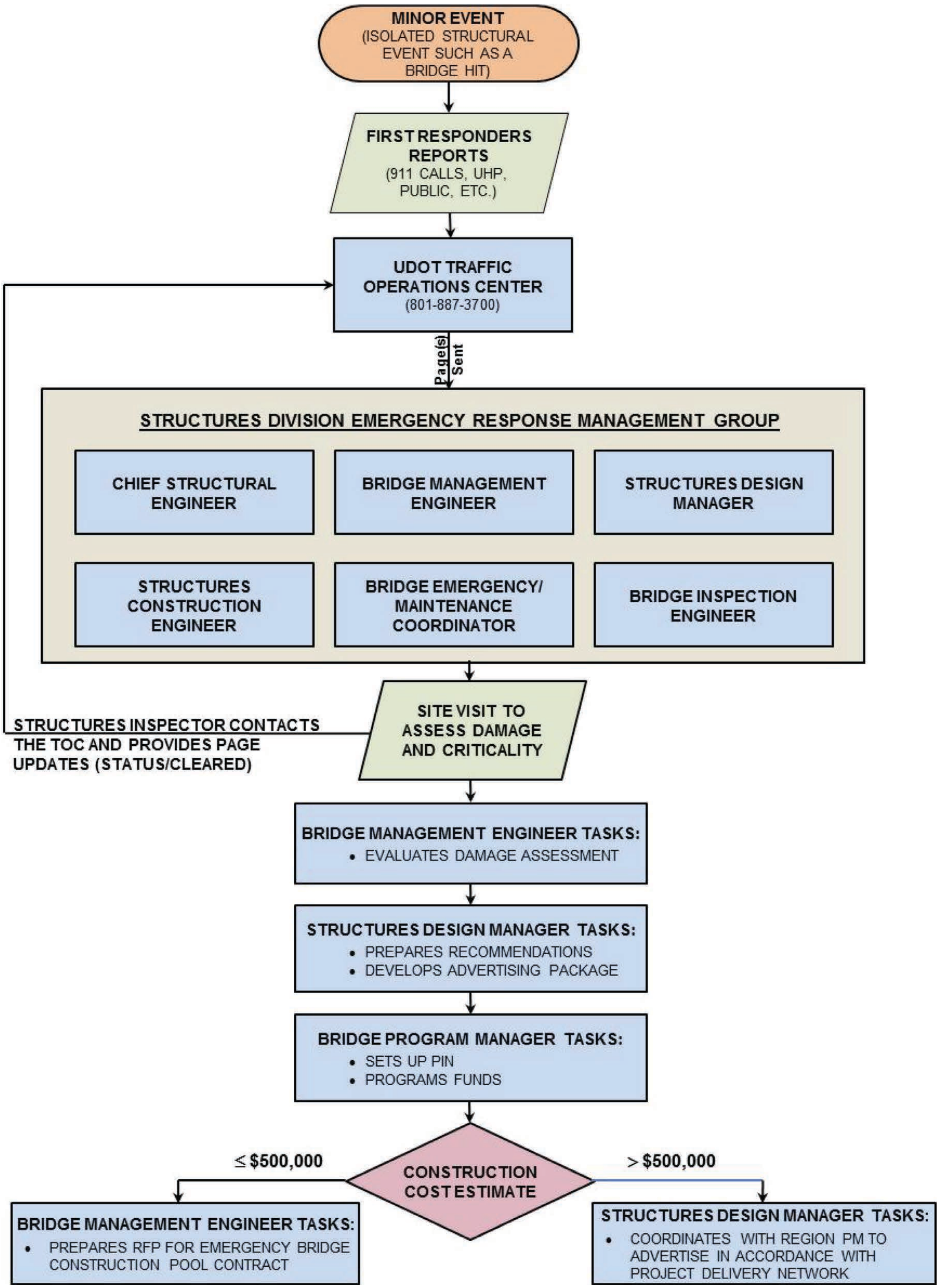
Equipment Use	Piece No.	Equipment: Description	Equipment: Size	Equipment Assignment: Inspection: Individual	Equipment Assignment: Inspection: Team	Equipment Assignment: Str. Unit	Equipment Assignment: Dist.	Comments
Traffic Safety	1	Red, yellow, and green ribbon			A			
	2	Red, yellow, and green chalk paint			A			
	3	Flags			E			
	4	Traffic cones			E			
	5	Triangular reflectors			E			
	6	"Bridge inspection ahead" signs			E			
	7	Shadow vehicle with arrow board			A		E	
	8	Towable platform crane			E			
	9	"Stoop" and "Slow" sign paddles				A	E	
	10	"Work Area Ahead" signs			E		E	
	11	"Flagman Ahead" sign			E		E	
	12	"Right Lane Closed" sign			E		E	
Cleaning Tools	1	Paint scraper		E	E			
	2	Wire brush		E	E			
	3	Ice scraper			R			
	4	Whisk broom		E	E			
	5	Regular broom			E			
	6	Shovel			E			
	7	Brush Ax			E			
	8	Pick Ax			R			
	9	Machete			E			
	10	Brush cutting looper			R			
	11	Bow saw			E			
	12	Chain saw (gas)	16″		R			
	13	Fuel container	2 gallon		R			
References	1	State map along with lifelines routes and bridge locations			E			
	2	Bridge Inspector's Reference Manual (BIRM)			E	E		Report No. FHWA-NH1-03-001

Equipment Use	Piece No.	Equipment		Equipment Assignment				Comments
				Inspection		Str. Unit	Dist.	
		Description	Size	Individual	Team			
References	3	Culvert Inspection Manual			E	E		FHWA-IP-86-2
	4	Recording and Coding Guide for the Structure Inventory and Appraisal of Nation's Bridges			R	E		FWHA-ED-89-044
	5	Bridge inventory book				A		
Documentation Materials	1	Assessment forms		A	A			
	2	Clipboard	8.5" x 11"	A	A			
	3	Pens, pencils, eraser		A	A			
	4	Stapler			E			
	5	Scientific calculator			E			
	6	Keel, permanent marking pens		E	E			
	7	Digital camera		R	E	E		
	8	Straight edge						
	9	Laptop computer						
	10	Permanent marker						
	11	GPS unit						
	12	Extra paper			A			

E = Essential
R = Recommended
A = Available
S = Special
Source: Modified from Pennsylvania DOT (2010).

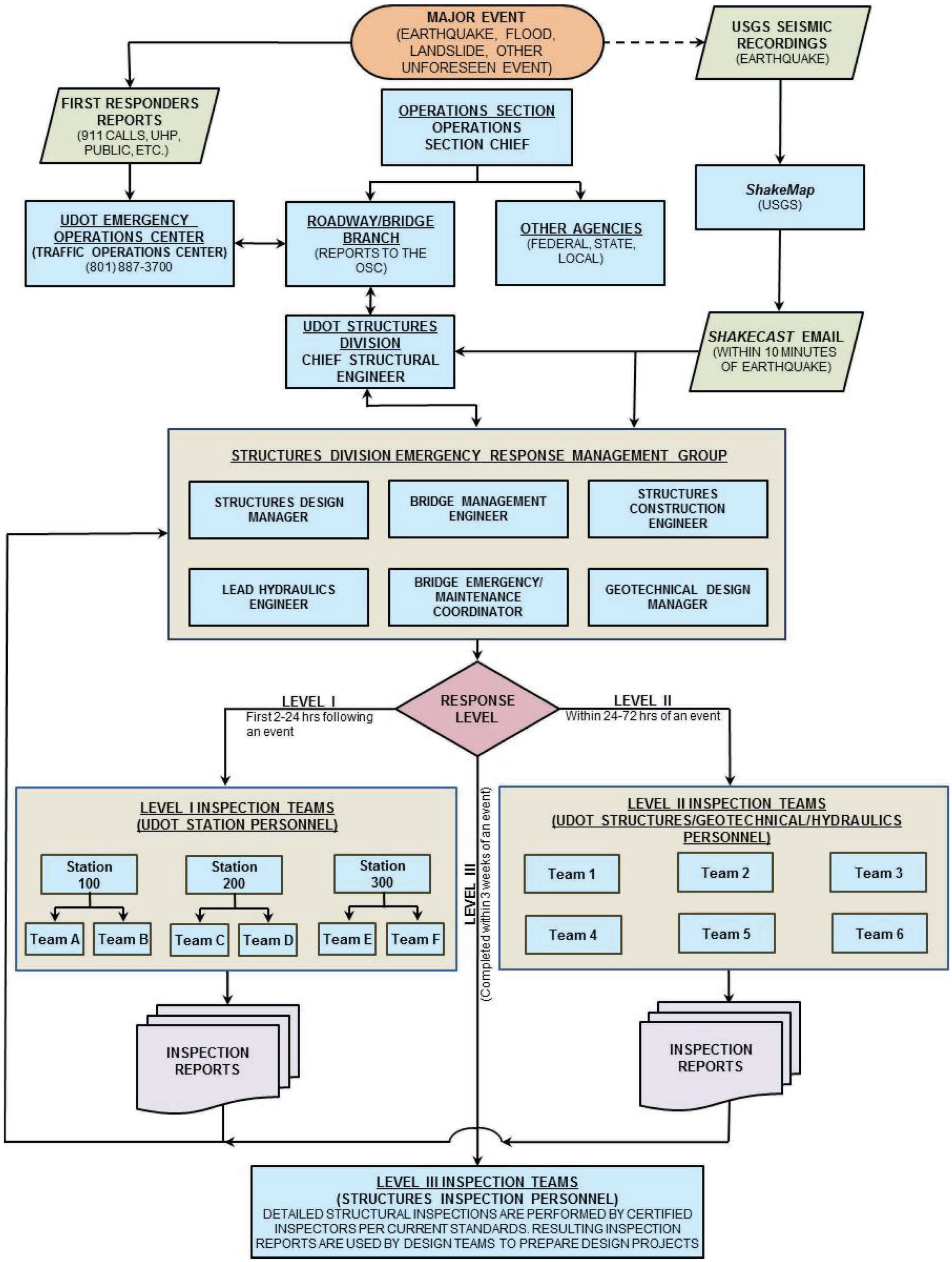
APPENDIX E

Example Communication Flowcharts



Source: Utah DOT (2014a).

Utah DOT communication flowchart for a minor event.



Source: Utah DOT (2014a).

Utah DOT communication flowchart for a major event.

APPENDIX F

Assessment Forms

Microsoft Word files for the following Preliminary Damage Assessment forms are available on the TRB website (www.trb.org) by searching for "NCHRP Research Report 833".

Preliminary Damage Assessment (PDA) Form – Bridges

Inspector 1 Name/ID:	______	Structure ID:	______	**PDA Outcome:**
Inspector 2 Name/ID:	______	Highway:	______	☐ INSPECTED (Green)
Agency:	______	Milepost:	______	☐ UNSAFE (Red)
Date and time:	______	Route Carried on:	______	
Latitude/Longitude:	______	Route Carried under:	______	
Structure material:	☐ Steel	☐ Concrete	☐ Other ______	

Damage Summary:	**Traffic Level:**	**Overall Comments:**
☐ 1 – None (0%)	☐ No traffic at all	______
☐ 2 – Slight (0-1%)	☐ Traffic on all lanes	______
☐ 3 – Light (1-10%)	☐ Traffic on some lanes	______
☐ 4 – Moderate (10-30%)	**Scour:**	______
☐ 5 – Heavy (30-60%)	☐ Unknown	______
☐ 6 – Major (60-100%)	☐ Unlikely	______
☐ 7 – Destroyed (100%)	☐ Likely, but cannot see	______
	☐ Definitely	

Feature Description:					**Notes: (additional notes on back)**
1. Approach/ Embankments	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
2. Parapets, Handrail, and Curb Line	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
3. Deck	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
4. Expansion Joint	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
5. Abutments and Wingwalls	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
6. Girder	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
7. Bearings	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
8. Bent Cap and Column	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
9. Foundation	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
10. Geotechnical	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Other______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below.

☐ **None** ☐ **DDA (Low Priority)** ☐ **DDA (High Priority)**

Record any recommendations:______________________________

____

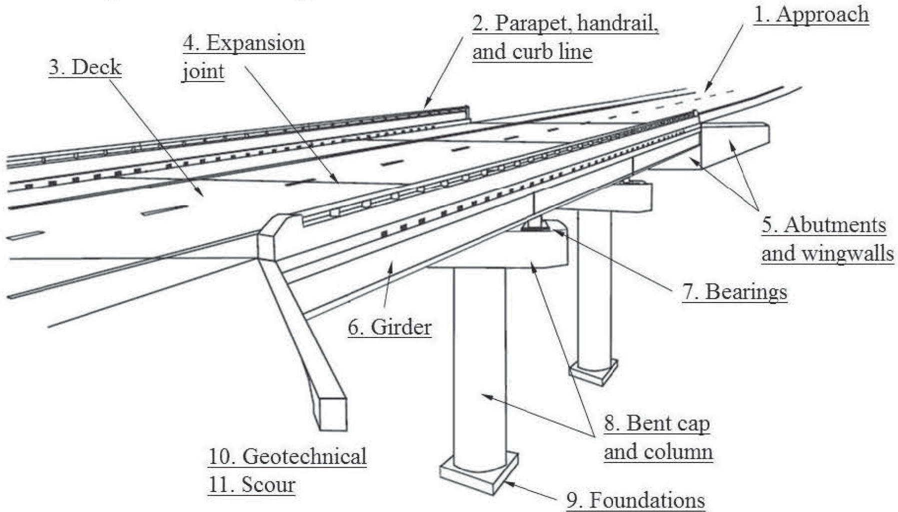
____

____

(QR Code)

Bridge assessment form (page 1/2).

Mark any areas of damage on the bridge:



Notes/Drawings/Comments continued:

Bridge assessment form (page 2/2).

Preliminary Damage Assessment (PDA) Form – Tunnels

Inspector 1 Name/ID: ______		Structure ID: ______				**PDA Outcome:**
Inspector 2 Name/ID: ______		Highway: ______				☐ INSPECTED (Green)
Agency: ______		Begin/End station: ______				☐ UNSAFE (Red)
Date and time: ______		Latitude/Longitude: ______				
Tunnel shape:	☐ Circular	☐ Rectangular	☐ Horseshoe	☐ Oval	☐ Other ______	
Liner type:	☐ Unlined rock	☐ Steel/Iron liner plate		☐ Masonry	☐ Precast concrete	
	☐ Shotcrete/Gunite	☐ Cast-In-Place concrete		☐ Timber	☐ Other ______	

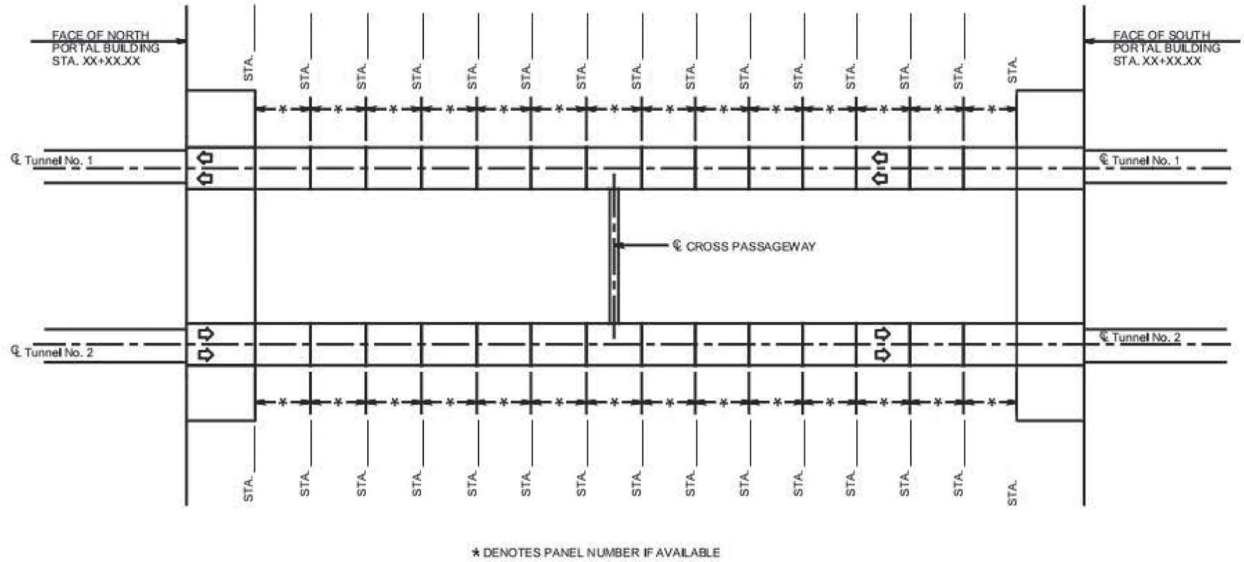
Damage Summary:	**Traffic Level:**	**Overall Comments:**
☐ 1 – None (0%)	☐ No traffic at all	______
☐ 2 – Slight (0-1%)	☐ Traffic on all lanes	______
☐ 3 – Light (1-10%)	☐ Traffic on some lanes	______
☐ 4 – Moderate (10-30%)	**Specific damage:**	______
☐ 5 – Heavy (30-60%)	☐ Fire	______
☐ 6 – Major (60-100%)	☐ Flooding	______
☐ 7 – Destroyed (100%)	☐ Other______	______

Feature Description:						**Notes: (additional notes on back)**
Roadway	1. Ceiling/Roof Slab	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	2. Invert Roadway Slab	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	3. Right Wall	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	4. Left Wall	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Upper Plenum (if present)	5. Underside of Roof	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	6. Top of Ceiling Slab	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	7. Right and Left Walls (if applicable)	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Lower Plenum (if present)	8. Underside of Invert Roadway Slab	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	9. Bottom of Plenum Slab	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	10. Right and Left Walls (if applicable)	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Misc.	11. Safety Walks and Railings	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
	Other______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______

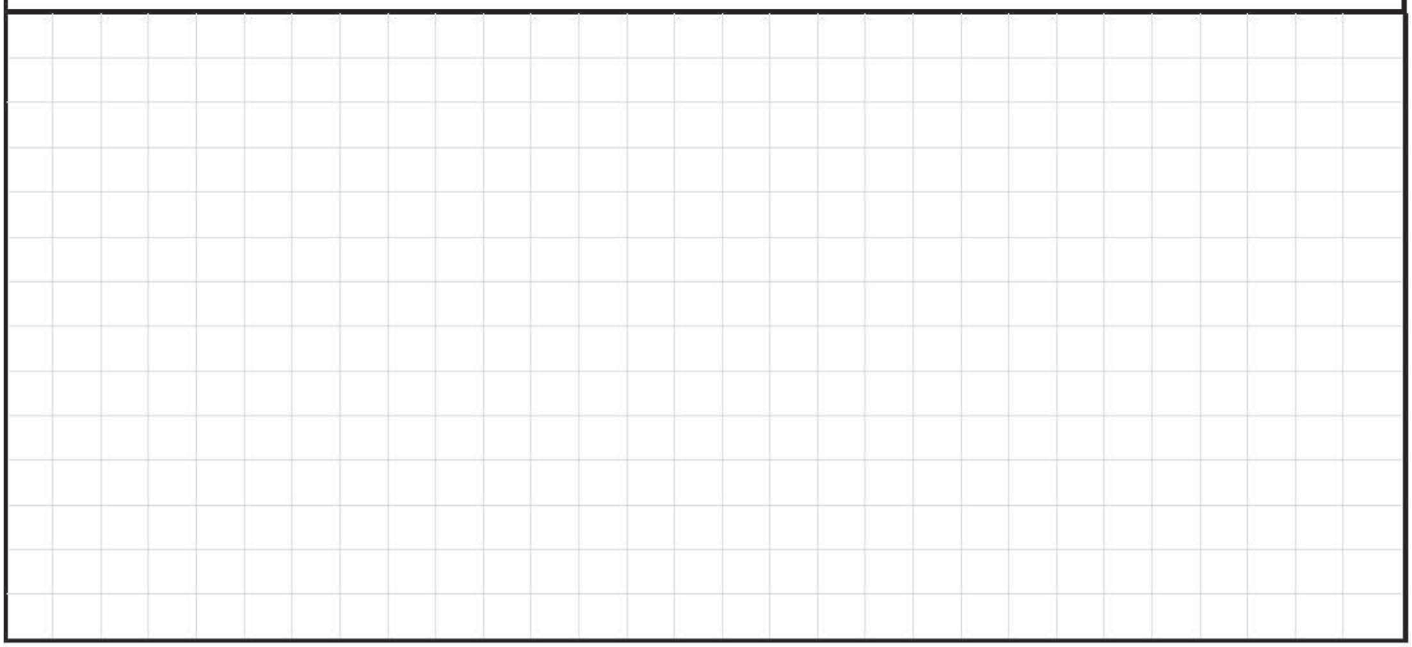
Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below. ☐ **None** ☐ **DDA (Low Priority)** ☐ **DDA (High Priority)** Record any recommendations:______ ______ ______	(QR Code)

Tunnel assessment form (page 1/2).

Tunnel inspection layout plan:



Notes/Drawings/Comments continued:



Tunnel assessment form (page 2/2).

Preliminary Damage Assessment (PDA) Form – Culverts

Inspector 1 Name/ID:	____________	Structure ID:	____________		**PDA Outcome:** ☐ INSPECTED (Green) ☐ UNSAFE (Red)
Inspector 2 Name/ID:	____________	Highway:	____________		
Agency:	____________	Milepost:	____________		
Date and time:	____________	Route Carried on:	____________		
Latitude/Longitude:	____________	Route Carried under:	____________		
Shape:	☐ Circular	☐ Arch	☐ Box	☐ Other ____________	
Material	☐ Concrete	☐ Metal	☐ Steel	☐ Plastic ☐ Other ________	

Damage Summary:	**Traffic Level:**	**Overall Comments:**
☐ 1 – None (0%)	☐ No traffic at all	____________
☐ 2 – Slight (0-1%)	☐ Traffic on all lanes	____________
☐ 3 – Light (1-10%)	☐ Traffic on some lanes	____________
☐ 4 – Moderate (10-30%)	**Scour:**	____________
☐ 5 – Heavy (30-60%)	☐ Unknown	____________
☐ 6 – Major (60-100%)	☐ Unlikely	____________
☐ 7 – Destroyed (100%)	☐ Likely, but cannot see	____________
	☐ Definitely	

Feature Description:					**Notes: (additional notes on back)**
1. Embankment	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
2. Roadway	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
3. Culvert condition	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
4. Headwall/ wingwall	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
5. Invert	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
6. Scour	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
Other____________	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
Other____________	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below.

☐ None **☐ DDA (Low Priority)** **☐ DDA (High Priority)**

Record any recommendations:____

____

____

____

(QR Code)

Culvert assessment form (page 1/2).

Sketch any areas of damage on the culvert:

Notes/Drawings/Comments continued:

Culvert assessment form (page 2/2).

Preliminary Damage Assessment (PDA) Form – Walls

Inspector 1 Name/ID: ______	Structure ID: ______		**PDA Outcome:**
Inspector 2 Name/ID: ______	Highway: ______		☐ INSPECTED (Green)
Agency: ______	Milepost: ______		☐ UNSAFE (Red)
Date and time: ______	Latitude/Longitude: ______		
Wall type: ☐ Masonry gravity	☐ Crib wall	☐ Sheet-pile wall	
☐ Cast-in-place gravity	☐ Bin wall	☐ Soldier pile wall	
☐ T-wall or L-wall	☐ Gabion wall	☐ Other______	

Damage Summary:	**Wall debris or damage:**	**Overall Comments:**
☐ 1 – None (0%) ☐ 2 – Slight (0-1%) ☐ 3 – Light (1-10%) ☐ 4 – Moderate (10-30%) ☐ 5 – Heavy (30-60%) ☐ 6 – Major (60-100%) ☐ 7 – Destroyed (100%)	☐ Presents a safety hazard or impedes traffic ☐ Poses a hazard if the structure is further damaged ☐ Can be cleaned by maintenance quickly ☐ Self contained	______

Feature Description:					**Notes: (additional notes on back)**
1. Wall performance	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
2. Corrosion/ weathering	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
3. Cracking/ breaking	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
4. Distortion/ deflection	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
5. Lost bearing/ missing elements	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
6. Primary______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
7. Primary______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
8. Primary______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
9. Secondary______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
10. Secondary______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______
Other______	☐ None	☐ Minor	☐ Moderate	☐ Severe	______

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below.

☐ None **☐ DDA (Low Priority)** **☐ DDA (High Priority)**

Record any recommendations:______

(QR Code)

Wall assessment form (page 1/2).

Sketch any areas of damage on the wall:

Notes/Drawings/Comments continued:

____
____
____
____
____
____

Wall assessment form (page 2/2).

Preliminary Damage Assessment (PDA) Form – Overhead Signs

Inspector 1 Name/ID: ____________	Structure ID: ____________	**PDA Outcome:**
Inspector 2 Name/ID: ____________	Highway: ____________	☐ INSPECTED (Green)
Agency: ____________	Milepost: ____________	☐ UNSAFE (Red)
Date and time: ____________	Latitude/Longitude: ____________	
Structure type: ☐ Span ☐ Cantilever	☐ Other ____________	

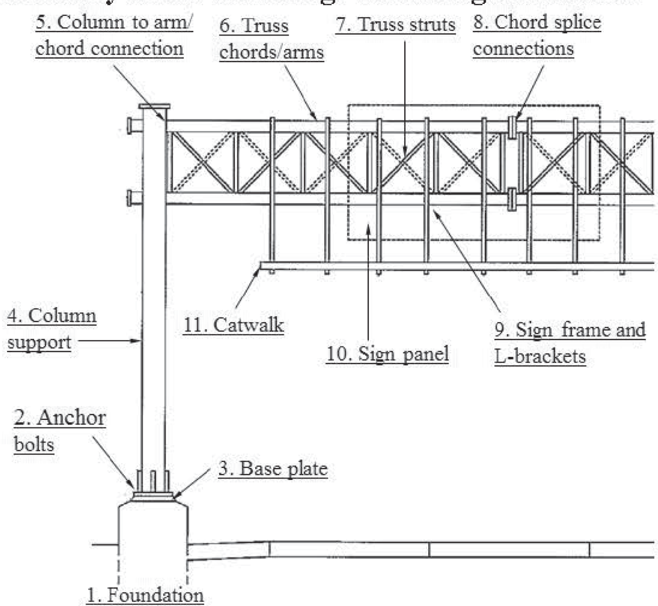
Damage Summary:	**Impeding traffic:**	**Overall Comments:**
☐ 1 – None (0%) ☐ 2 – Slight (0-1%) ☐ 3 – Light (1-10%) ☐ 4 – Moderate (10-30%) ☐ 5 – Heavy (30-60%) ☐ 6 – Major (60-100%) ☐ 7 – Destroyed (100%)	☐ Presents a safety hazard or impedes traffic ☐ Poses a hazard if the structure is further damaged ☐ Can be cleaned by maintenance quickly ☐ Self-contained	____________

Feature Description:					**Notes: (additional notes on back)**
1. Foundation	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
2. Anchor bolts	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
3. Base plate	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
4. Column support	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
5. Column to arm/chord connection	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
6. Truss chord/arms	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
7. Truss struts	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
8. Chord splice connections	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
9. Sign frame and L-brackets	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
10. Sign panel	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
11. Catwalk	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
Other____________	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________
Other____________	☐ None	☐ Minor	☐ Moderate	☐ Severe	____________

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below. **☐ None** **☐ DDA (Low Priority)** **☐ DDA (High Priority)** Record any recommendations____________	(QR Code)

Overhead sign assessment form (page 1/2).

Mark any areas of damage on the sign structure:



Notes/Drawings/Comments continued:

____

____

____

____

____

____

Overhead sign assessment form (page 2/2).

Preliminary Damage Assessment (PDA) Form – Bridges

Inspector 1 Name/ID:	J. CLOUSEA/12345	Structure ID:	BR. No. 53 0730	**Final Posting:**
Inspector 2 Name/ID:	H. POIROT/54321	Structure Name:	SAN FERNANDO RD. OH	☐ INSPECTED (Green)
Agency:	CALTRANS	Highway:	I5	
Date and time:	5/23/15 10:22 AM	Milepost:	43.84	
Latitude:	34°20'07.42 N	Route Carried on:	I5 NB	☒ UNSAFE (Red)
Longitude:	118°30'31.29 W	Route Carried under:	SAN FERNANDO RD.	
Structure material:	☐ Steel ☒ Concrete ☐ Other			

Damage Summary:	**Traffic Level:**	**Overall Comments:**
☐ 1 – None (0%)	☒ No traffic at all	DAMAGE CONCENTRATED @ A1, B2
☐ 2 – Slight (0-1%)	☐ Traffic on all lanes	B3, B4, B5, A6 APPEAR UNDAMAGED
☐ 3 – Light (1-10%)	☐ Traffic on some lanes	
☒ 4 – Moderate (10-30%)	**Scour:**	POUNDING + BEARING DAMAGE @ A1
☐ 5 – Heavy (30-60%)	☐ Unknown	
☐ 6 – Major (60-100%)	☒ Unlikely	SHEAR CRACKS @ B2 COLUMNS
☐ 7 – Destroyed (100%)	☐ Likely, but cannot see	
	☐ Definitely	

Feature Description:					**Notes: (additional notes on back)**
1. Approach/ Embankments	☒ None	☐ Minor	☐ Moderate	☐ Severe	
2. Parapets, Handrail, and Curb Line	☐ None	☒ Minor	☐ Moderate	☐ Severe	HANDRAIL MISALIGNMENT + SEPARATIONS @ A1
3. Deck	☐ None	☒ Minor	☐ Moderate	☐ Severe	MINOR CRUSHING + SPALLING @ A1 EXP. JT.
4. Expansion Joint	☐ None	☐ Minor	☐ Moderate	☒ Severe	7" VERT. + 5" HORIZ. OFFSET @ A1
5. Abutments and Wingwalls	☐ None	☐ Minor	☐ Moderate	☒ Severe	LG. CRACK ON S. SIDE OF A1 WINGWALL
6. Girder	☐ None	☐ Minor	☒ Moderate	☐ Severe	CLOSED FLEXURAL CRACKS NEAR B2 (TOP) + LOCALIZED SPALLING OF COVER (BOT)
7. Bearings	☐ None	☐ Minor	☐ Moderate	☒ Severe	UNSEATING OF A1 BEARINGS
8. Bent Cap and Column	☐ None	☐ Minor	☐ Moderate	☒ Severe	LG. STEEP CRACKS @ B2 COLUMNS
9. Foundation	☒ None	☐ Minor	☐ Moderate	☐ Severe	
10. Geotechnical	☒ None	☐ Minor	☐ Moderate	☐ Severe	
Other________	☐ None	☐ Minor	☐ Moderate	☐ Severe	

Recommendations: Choose a recommendation based on the evaluation and team judgment. DDA evaluations should only be recommended with an UNSAFE posting. Provide comments on the recommendations below.

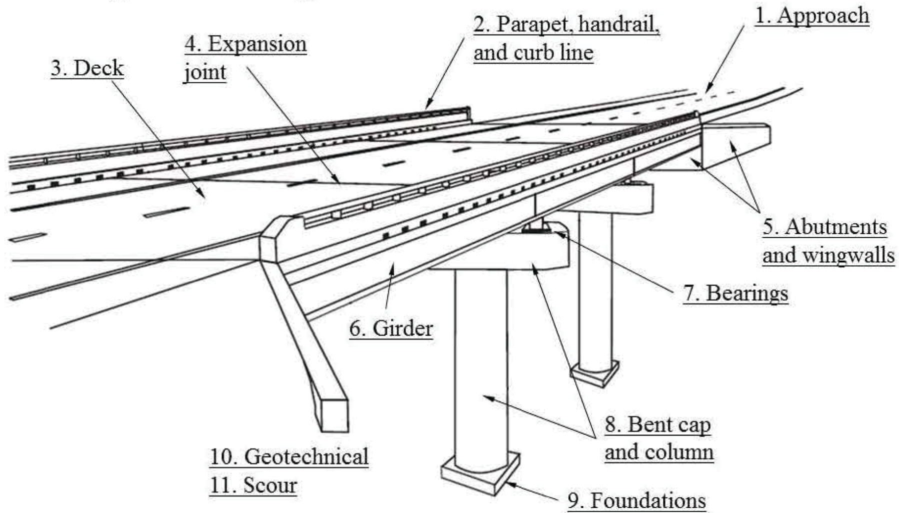
☐ **None** ☐ **DDA (Low Priority)** ☒ **DDA (High Priority)**

Record any recommendations:____________________

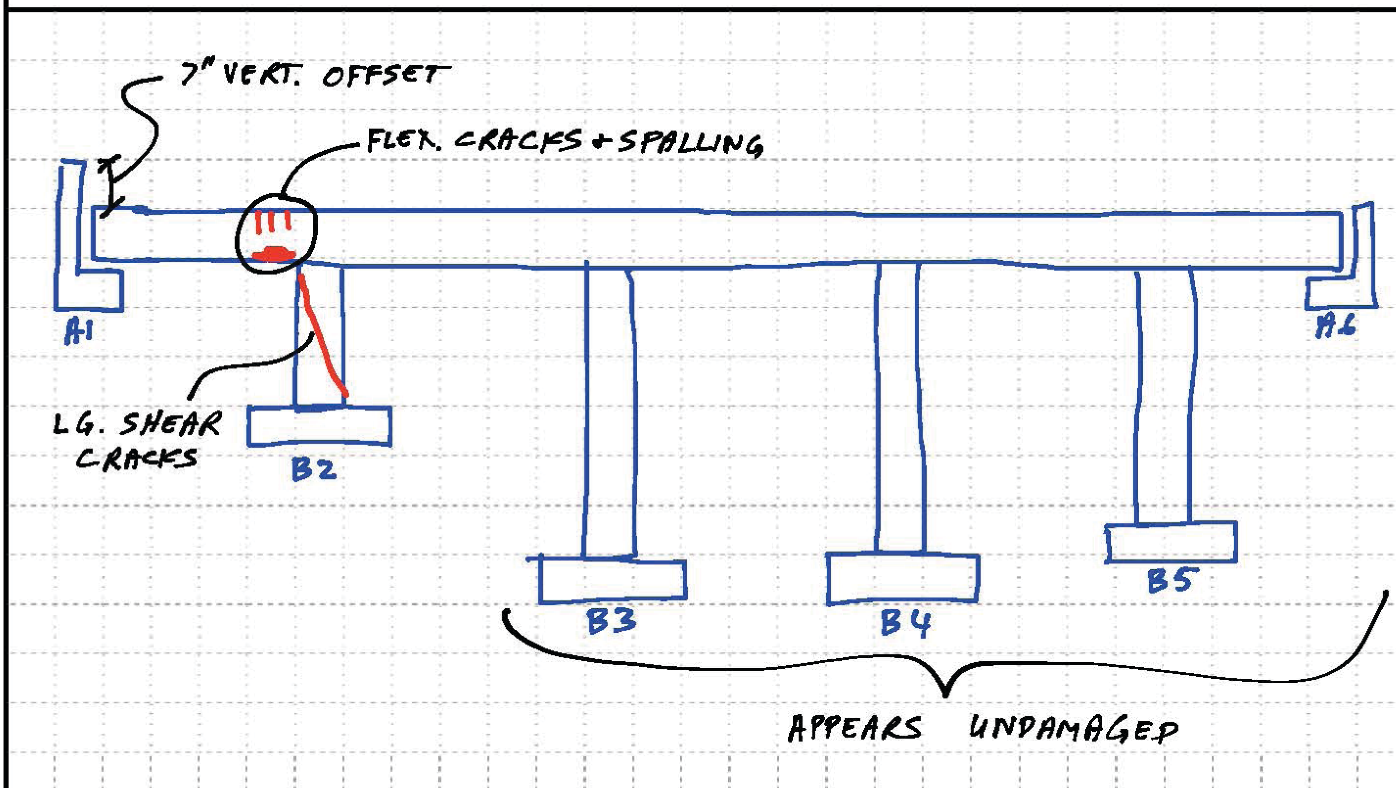
(QR Code)

Example of a completed bridge assessment form (page 1/2).

Mark any areas of damage on the bridge:



Notes/Drawings/Comments continued:



Example of a completed bridge assessment form (page 2/2).

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Acronyms and Abbreviations

AADT	Average annual daily traffic
ADT	Average daily traffic
AFWS	Automated Flood Warning System
CPG	Comprehensive Preparedness Guide
DDA	Detailed Damage Assessment
DHS	Department of Homeland Security
DOT	Department of Transportation
EF	Enhanced Fujita
EI	Extended Investigation
EMC	Emergency Management Coordinator
ENS	Earthquake Notification Services
EOP	Emergency Operations Plan
EPP	Emergency Preparedness Plan
ERP	Emergency Response Plan
ERT	Emergency Response Team
ETN	Emergency Telephone Network
FEMA	Federal Emergency Management Agency
FFG	Flash Flood Guidance
FR	Fast Reconnaissance
GETS	Government Emergency Telecommunications Service
GIS	Geographic Information System
GPS	Global Positioning System
HF	High Frequency
HGV	Heavy goods vehicle
ICS	Incident Command System
IT	Information Technology
MACS	Multiagency Coordination System
MBE	Manual for Bridge Evaluation
MCOV	Mobile Communications Office Vehicle
MERS	Mobile Emergency Response Support
MSE	Mechanically Stabilized Earth
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NIMS	National Incident Management System
NIPP	National Infrastructure Protection Plan
NOAA	National Oceanic and Atmospheric Administration
NTWC	NOAA Tsunami Warning Center
NWS	National Weather Service

OEM	Office of Emergency Management
PDA	Preliminary Damage Assessment
PDAR	Preliminary Damage Assessment Responder
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PTWC	Pacific Tsunami Warning Center
QR	Quick Response
RDS	Rapid Deployment Solutions
SDC	Seismic Design Category
SHA	State Highway Agency
THIRA	Threat and Hazard Identification and Risk Assessment
UAV	Unmanned aerial vehicle
UHF	Ultra High Frequency
USGS	United States Geological Survey
VHF	Very High Frequency
VoIP	Voice-Over-Internet Protocol
WPS	Wireless Priority Service

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.
Critical Structure	A structure that must remain open to all traffic after a design event and be usable by emergency vehicles and for security defense purposes immediately after a large event (e.g., event with a 2,500-year return period).
Detailed Damage Assessment	Provides an evaluation of structural damage and decisions on use restriction after the Preliminary Damage Assessment.

Term	Definition
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.
Essential Structure	A structure that should, at minimum, be open to emergency vehicles and for security purposes immediately after a design earthquake (e.g., event with a 1,000-year return period).
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.
Extreme Wind Warning	Extreme sustained winds of a major hurricane (115 mph or greater), usually associated with the eyewall, are expected to begin within an hour.
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.

Term	Definition
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.
Major Flooding	Floods with 50- to 100-year recurrence interval are assumed to cause major flooding.
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.”
Mercalli Scale	An earthquake scale from I–XII based on the observations of people who experience the earthquake.
Minor damage	The element shows cosmetic or non-structural damage.
Minor Flooding	Floods with 5- to 10-year recurrence interval are assumed to cause minor flooding.
Moderate damage	The element has experienced structural or geotechnical damage.
Moderate Flooding	Floods with 15- to 40-year recurrence interval are assumed to cause moderate flooding.
Moment Magnitude Scale	A scale measuring the total moment release of an earthquake on a base 10 logarithmic scale.
Other Structure	These structures include all structures that are not classified as critical or essential.
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.

Term	Definition
Reporting Station	These are the designated stations where Preliminary Damage Assessment responders will report to the managing engineer.
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.
Technological Training	Training on the use of technology to perform assessments.
Tornado Warning	A tornado has been sighted by spotters or indicated on radar and is occurring or imminent in the warning area.
Tornado Watch	Conditions are conducive to the development of tornados in and close to the watch area.
Tsunami Advisory	A tsunami advisory is issued due to the threat of a potential tsunami which may produce strong currents or waves.
Tsunami Warning	A tsunami warning is issued when a potential tsunami with significant widespread inundation is imminent or expected.
Tsunami Watch	A tsunami watch is issued to alert emergency management officials and the public of a tsunami which may later impact the watch area.
UNSAFE	This classification utilizes a red color and indicates the structure has experienced severe damage or collapsed and cannot function properly under traffic loads.
Wind Advisory	Issued when sustained winds of 31 to 39 mph are forecast for 3 hours or longer, or wind gusts of 46 to 57 mph for any direction.

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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