ASSESSING, CODING AND MARKING OF HIGHWAY STRUCTURES IN EMERGENCY SITUATIONS

M. Veletzos\(^1\), M.J. Olsen\(^2\), A.R. Barbosa\(^3\), P. Burns\(^4\), Z. Chen\(^5\), G. Roe\(^6\), and K. Tabrizi\(^7\)

ABSTRACT

A recent survey of state highway agencies (SHA) indicated that only 22% of SHAs have a formal procedure for assessing highway structures in emergency situations. 30% of SHAs indicated that they have an informal process whereas 40% of SHAs do not have any assessment process at all. Furthermore, very large scale disaster events, such as hurricanes or earthquakes, are likely to cross state borders and rapidly deplete local resources. These events often require resources from other states to assist in the recovery efforts and coordination with multiple entities. To minimize confusion during response and maximize community resilience, it is important for all states to utilize the same approach to assessing, coding, and marking of highway structures in emergency situations. This paper describes the detailed process for assessing, coding, and marking of highway structures in emergency situations that was developed in NCHRP Report 833. This process is based on best practices from across the United States and is applicable to a wide range of highway structures and emergency situations.

\(^1\)Associate Professor, Department of Civil Engineering, Merrimack College, North Andover, MA 01810 (email: veletzosm@merrimack.edu)
\(^2\)Associate Professor, School of Civil and Construction Engineering, Oregon State University, Corvallis, OR 97331 (email: olsen@oregonstate.edu)
\(^3\)Assistant Professor, School of Civil and Construction Engineering, Oregon State University, Corvallis, OR 97331 (email: andre.barbosa@oregonstate.edu)
\(^4\)Design Engineer, Magnusson Klemencic Associates, Seattle, WA. 98101 (email: patrickburns32@gmail.com)
\(^5\)Associate Professor, Dept. of Civil and Mechanical Engineering, University of Missouri-Kansas City, Kansas City, MO 64110 (email: chenzhiq@umkc.edu)
\(^6\)Principal Engineer, MPN Components, Hampton, NH 03842 (email: gene.roe@lidarnews.com)
\(^7\)Executive Vice-President, Advanced Infrastructure Design, Inc., Hamilton Township, NJ 08691 (email: ktabrizi@aidpe.com)

ASSESSING, CODING AND MARKING OF HIGHWAY STRUCTURES IN EMERGENCY SITUATIONS

M. Veletzos¹, M.J. Olsen², A.R Barbosa³, P. Burns⁴, Z. Chen⁵, G. Roe⁶, and K. Tabrizi⁷

ABSTRACT

A recent survey of state highway agencies (SHA) indicated that only 22% of SHAs have a formal procedure for assessing highway structures in emergency situations. 30% of SHAs indicated that they have an informal process whereas 40% of SHAs do not have any assessment process at all. Furthermore, very large scale disaster events, such as hurricanes or earthquakes, are likely to cross state borders and rapidly deplete local resources. These events often require resources from other states to assist in the recovery efforts and coordination with multiple entities. To minimize confusion during response and maximize community resilience, it is important for all states to utilize the same approach to assessing, coding, and marking of highway structures in emergency situations. This paper describes the detailed process for assessing, coding, and marking of highway structures in emergency situations that was developed in NCHRP Report 833. This process is based on best practices from across the United States and is applicable to a wide range of highway structures and emergency situations.

Introduction

Highway structures are critical components of the United States’ transportation infrastructure and are important components of our communities. Assessing, coding, and marking of highway structures are necessary for ensuring public safety in the event of emergencies. Several state highway agencies (SHAs) have adopted processes for assessing, coding, and marking of highway structures in the event of emergencies resulting from natural or man-made disasters. However, these processes do not provide uniform means for conducting these assessments or a common form of coding and marking. In addition, 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 with assistance. This lack of consistency in responding to large scale emergencies lengthens the duration of the recovery efforts and weakens overall community resiliency. Thus, there is a need for employing uniform processes for conducting these assessments and guidelines for coding and marking.

Addressing this significant need, the Project NCHRP 14-29 was funded by the Transportation Research Board through the National Cooperative Highway Research Program. This paper provides a high level summary of the work completed in this project, which had the primary objectives of developing: (a) A process for assessing a wide range of highway structures in variety of emergency situations, (b) Guidelines for coding and marking, and (c) Training and implementation material. The deliverables developed to satisfy these objectives were prepared as standalone documents, collectively published in NCHRP Report #833, which aims to help
facilitate acceptance and adoption by AASHTO and other organizations generally responding to emergency situations affecting highway structures [1, 2, 3]. This paper summarizes the major components of this report, which include:

- State-of-The-Art and State-of-The-Practice: Literature Review and Questionnaire
- Assessment Process Manual
- Coding and Marking Guidelines, and
- Additional Resources

The reader is referred to NCHRP #833 for additional details beyond the limited information presented in this paper.

**State-of-The-Art and State-of-The-Practice: Literature Review and Questionnaire**

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

A questionnaire was distributed in early spring 2014 to the membership of relevant AASHTO Subcommittees and to state TRB representatives [1]. A total of 59 complete responses representing all 50 state highway agencies were obtained. The respondents consisted of personnel from maintenance, operations, bridge, and structures divisions. Of these, the respondents contained a mix of inspection/maintenance engineers, bridge engineers, and managers. Hence, the questionnaire response group contains input from the various divisions and personnel responsible for conducting structural assessments and maintaining those structures. This questionnaire enabled the team to obtain current SHA procedural manuals that are difficult to find via conventional means. A primary finding from the questionnaire is that only 22% of SHAs have a formal procedure for assessing highway structures in emergency situations and only 30% have formal guidelines for coding and marking during an emergency situation (see Figure 1). In addition, 70% of SHAs have only informal or no formal assessment process in place and the majority of SHAs have only informal or no coding and marking guidelines for emergency situations [1].
Figure 1: Response to questions related to the availability of written assessment procedures and coding and marking guidelines of highway structures in emergency situations [1].

Assessment Process Manual

The Assessment Process Manual (APM) [2] defines a clear process and provides the tools necessary to effectively and uniformly assess, code, and mark highway structures in emergency situations. The primary audience for the APM includes senior managers, engineers, and inspectors who will have the responsibility to coordinate emergency response and determine if structures are safe for the travelling public during and after emergency events. The assessment process was largely based on approaches currently used by several state agencies and SHAs including the New York State Department of Transportation, Washington State Department of Transportation, Michigan State Police, Utah Department of Transportation and California Department of Transportation [4, 5, 6, 7].

The assessment process was developed to fit easily within the context of the overall emergency response lifecycle and includes: pre-event planning; training; appropriate technology usage; prioritization strategies; coding and marking; coordination; communication; inspection procedures; and redundancy. The assessment process was developed based in large part on its ability to satisfy the following attributes: Practical, Cost-effective, Ease of Use, Multi-tiered, Redundant, Flexible, Assessment Rate, and Fail-safe. Important components of the assessment process are described below and include the planning and preparation phase, assessment stages and response levels.

Planning and Preparation

Planning and preparation are necessary to anticipate as many of the likely emergency scenarios as possible so that the needed response can be identified, planned, and effectively coordinated
with a minimum of crisis management. Proper planning can ensure that limited resources for data collection (including installation, training, and maintenance of equipment for inspection) are available and optimally allocated. During this vital planning phase, regional factors, interagency needs, and communication issues will be identified and addressed in a non-emergency environment. Access by inspectors to all available information, which can vary significantly, can be planned and tested under simulated event conditions (e.g., Shakeout events). Additional details and recommendations can be found in the Assessment Process Manual [2].

Assessment Stages

The assessment of highway structures during an emergency situation will be accomplished using a four-stage process: Fast Reconnaissance (FR); Preliminary Damage Assessment (PDA); Detailed Damage Assessment (DDA); and Extended Investigation (EI). The four stages are based on methods currently in use throughout the United States [4, 5, 8, 9]. 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 to maximize public safety. Figure 2 presents an overview of the assessment process for a single structure and the interaction of the assessment stages along with the possible coding and marking classifications for a structure.

Table 1 summarizes the objective and primary deliverables of each assessment stage.

Table 1: Summary of Assessment Stages

<table>
<thead>
<tr>
<th>Assessment Stage</th>
<th>Objective</th>
<th>Primary Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR</td>
<td>Preparation</td>
<td>Enrollment in the response</td>
</tr>
<tr>
<td>PDA</td>
<td>Preliminary Damage Assessment</td>
<td>Identification of damaged structures</td>
</tr>
<tr>
<td>DDA</td>
<td>Detailed Damage Assessment</td>
<td>Quantitative assessment of damage</td>
</tr>
<tr>
<td>EI</td>
<td>Extended Investigation</td>
<td>Further investigation and repair/reconstruction planning</td>
</tr>
</tbody>
</table>

Response Levels

Response levels relate to the immediacy of the response, the level of resources required, and the effort that will be put into a response during an emergency event. They are essentially a status alert that can help ensure all agencies and personnel are on the same page as to the magnitude of the response effort. As an example, a large earthquake (e.g., $M_w$ 7.0) creating damage over a dispersed geographic region will require a different method of response for structural assessment.
compared to a smaller event (e.g., Mw 4.0 earthquake) where damages will be more localized and of lesser intensity. Use of response levels can help SHAs 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.

Table 1: Damage assessment stages [2].

<table>
<thead>
<tr>
<th>Type</th>
<th>Fast Reconnaissance (FR)</th>
<th>Preliminary Damage Assessment (PDA)</th>
<th>Detailed Damage Assessment (DDA)</th>
<th>Extended Investigation (EI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
<td>Global perspective</td>
<td>Rapid route reconnaissance</td>
<td>Detailed inspection</td>
<td>Special study to address a particular concern</td>
</tr>
<tr>
<td>Scope</td>
<td>All structures in affected area</td>
<td>All structures in affected area, starting with priority routes</td>
<td>Structure and site-specific</td>
<td>Site-specific, as needed</td>
</tr>
<tr>
<td>Inspection Method</td>
<td>Helicopter, small fixed wing aircraft, unmanned aerial vehicles, and other “Fast” methods</td>
<td>Drive-through with quick stop at each structure</td>
<td>Inspection and special access equipment as needed, load rating and remaining strength analysis</td>
<td>Any special equipment that is needed</td>
</tr>
<tr>
<td>Personnel</td>
<td>Chief Engineers or Managing Engineer (ME) in aircraft or vehicle; specialized technicians as needed; the public</td>
<td>PDARs – Trained emergency responders (Maintenance &amp; Operations crews, Design Engineers)</td>
<td>Routine inspectors and specialists (e.g., Structural, Geotechnical, Hydrological, Mechanical, Materials)</td>
<td>Specialists (e.g., Structural, Geotechnical, Hydrological, Mechanical, Materials)</td>
</tr>
<tr>
<td>Timeframe</td>
<td>Immediate (within 4-6 hours)</td>
<td>Immediate (within 24 hours)</td>
<td>Start A.S.A.P. (usually within 8 hours) and continue as necessary</td>
<td>Subsequent to DDA</td>
</tr>
<tr>
<td>Outcome</td>
<td>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</td>
<td>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</td>
<td>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</td>
<td>Code and mark as necessary Detailed damage analysis Provide specific recommendations on necessary restrictions and/or repair Approximate cost estimate for remedial work</td>
</tr>
<tr>
<td>Deliverable</td>
<td>Reconnaissance report with maps, geo-referenced photos and/or video that defines the affected region</td>
<td>Digital PDA form/database (one entry per structure) and physical marking on the structure</td>
<td>DDA Report for each structure and Daily Summary Report</td>
<td>Special engineering report</td>
</tr>
<tr>
<td>Coding Options</td>
<td>UNSAFE</td>
<td>UNSAFE, INSPECTED</td>
<td>UNSAFE, LIMITED USE, INSPECTED</td>
<td>UNSAFE, LIMITED USE, INSPECTED</td>
</tr>
</tbody>
</table>

The APM presents four response levels and provides recommendations on criteria for each level. However, each SHA must determine the appropriate criteria for each level of response based on local hazards and knowledge of design practices in the state. During an emergency event, SHAs can decide to escalate or reduce a response level as more information becomes available.

Figure 3 provides a process flowchart for the emergency response following an emergency event. Fast reconnaissance should be conducted for all response levels, however, the
specific techniques implemented should be refined according to the severity and geographic extent of the emergency event. Upon receiving an emergency notification, emergency management officials should first validate the warning. Once the warning has been confirmed, structure priority routes should be reviewed and planned for inspection. Response levels corresponding to different emergency events are detailed in the Assessment Process Manual.

Figure 3: Response level process flowchart [2].
Coding and Marking Guidelines

An integral part of the assessment process is to communicate the results via coding and marking (i.e., providing a damage rating and labeling the structure through digital and/or physical means). The Coding and Marking Guidelines (CMG) [3] were developed as a field guide and intended to be the primary resource for personnel conducting field assessments, that is, preliminary damage assessment responders (PDARs). This document outlines relevant background information on emergency situations and the overall assessment process. Important aspects of the CMG are outlined below.

**Damage Assessment**

The CMG provides detailed guidance on damage assessment of highway structures, and includes images showing examples of various damage levels (i.e., minor to severe) of a variety of highway structural components (i.e. bridge columns, tunnel walls). Assessment forms are included to guide PDARs on important components to assess each type of highway structure (see Figure 4). The forms include a location for an overall damage summary that can be aggregated to estimate the overall impact of the emergency situation.

<table>
<thead>
<tr>
<th>Damage Severity:</th>
<th>Traffic Level:</th>
<th>Overall Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 - None (0%)</td>
<td>No traffic at all</td>
<td></td>
</tr>
<tr>
<td>C2 - Light (1-25%)</td>
<td>Traffic on all lanes</td>
<td></td>
</tr>
<tr>
<td>C3 - Moderate (26-74%)</td>
<td>Traffic on major lanes</td>
<td></td>
</tr>
<tr>
<td>C4 - Severe (75-100%)</td>
<td>Traffic on minor lanes</td>
<td></td>
</tr>
<tr>
<td>C5 - Heavy (100%)</td>
<td>Damage</td>
<td></td>
</tr>
<tr>
<td>C6 - Major (100%)</td>
<td>Damage</td>
<td></td>
</tr>
<tr>
<td>C7 - Disaster (100%)</td>
<td>Damage</td>
<td></td>
</tr>
</tbody>
</table>

**Recommending a New Recommendation**

A recommendation should only be made if the condition of the bridge is unacceptable. Provide comments on the recommendations below.

- **G1** - High Priority
- **G2** - Medium Priority
- **G3** - Low Priority

<table>
<thead>
<tr>
<th>Recommendation:</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td></td>
</tr>
<tr>
<td>G2</td>
<td></td>
</tr>
<tr>
<td>G3</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Example of the two-sided PDA bridge form. Note that a separate form is available for each highway structure considered.
Coding and Marking Process

A coding and marking system was developed to support uniform communication between inspectors, maintenance crews, engineers, and others as necessary. The terms INSPECTED, LIMITED USE, and UNSAFE were chosen to be consistent with the process used for buildings (i.e., ATC-20).

All inspected structures within the impacted region of the emergency situation should be marked both physically and digitally after conducting an assessment and establishing the coding for the structures. 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 with the appropriate coding option (see Figure 5). For example, this would be on the right hand side of the approach to the bridge (i.e., on railings or fixed structural element at both bridge abutments). Structures shall be marked digitally in a central database and/or GIS map that is accessible by authorized staff with a secure connection. The use of quick response (QR) codes on the placard in concert with smart devices (i.e., smartphones or tablets), or standalone 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 (i.e., close structure, close lane), and initials of the PDARs.

After undergoing PDA, highway structures should be posted with one of two placards: INSPECTED or UNSAFE (refer to Figure 5). If a structure is tagged UNSAFE during a PDA evaluation, it will be further evaluated using DDA. During DDA, highway structures are posted with one of three decals on a new/updated placard: INSPECTED, LIMITED USE, or UNSAFE. This posting lets the SHA, respondents, inspectors, and the public know the condition of the structure as well as the date and time the assessment was performed. The system used for posting a highway structure and the definition of each posting category are summarized in Table 2.
Table 2: Highway structure coding and marking classifications for PDA and DDA.

<table>
<thead>
<tr>
<th>Marking Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSPECTED (Green)</td>
<td>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 appears to be fully intact. No restrictions on use.</td>
</tr>
<tr>
<td>LIMITED USE (Yellow)</td>
<td>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.</td>
</tr>
<tr>
<td>UNSAFE (Red)</td>
<td>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.</td>
</tr>
</tbody>
</table>

**Additional Resources**

A number of additional resources were developed as part of this project, which include:

- **Research Overview** – This document describes the details of the research project and includes the complete literature review and the questionnaire results. In addition, this document includes an evaluation of assessment technologies and coding and marking practices, a description of training materials, and recommends an implementation plan.
- **Smart App Developers Guide** - A technical manual that provides guidelines for developing a mobile devices-based Smart App for PDA responders. This manual includes guidelines for developing interfaces, basic functions, and server or cloud-side services to support the smart functions. The Smart App primarily aims to automate the manual and paper-based assessing, coding, and marking procedures. [10].
- **Training Materials** – Materials for four training workshops were created that tailor content to a specific audience based in their role in the emergency response. These training workshops vary in length from 30 minutes to 8 hours and are: General Training, Managing Engineer Training, Preliminary Damage Assessment Respondent Training, PDAR Quick Refresher Course.

**Conclusions**

This paper provides an overview of a comprehensive and uniform process for assessing, coding, and marking highway structures in emergency situations (NCHRP Report #833). This process is applicable to a wide range of highway structures and emergency situations. Several documents are available for immediate use by state highway agencies and other interested agencies and personnel. The Assessment Process Manual describes the complete process including pre-event planning, assessment stages and response levels. The Coding and Marking Guidelines is a field guide that provides responders with the necessary information to assess, code and mark highway...
structures in emergency situations, and includes guidance on differentiating minor, moderate and severe damage to structural components as well as assessment forms for a variety of highway structural. A Smart App Developers Guide was produced that assists in the creation of an App for mobile smart devices that can streamline and simplify the individual structural assessments. Materials for four training workshops were developed to facilitate the implementation of this comprehensive assessment process. The uniform processes and guidelines described in this paper will assist state highway agencies to quickly and effectively respond to regional emergency events, both within states and across state borders, and will ultimately serve as important resources to help strengthen community resilience.

Acknowledgments

Project NCHRP 14-29 was funded by the Transportation Research Board through the National Cooperative Highway Research Program. This project could not have been completed without the assistance of those who responded to the questionnaire and provided the research team with information regarding current processes of state highway agencies. In addition, we are thankful for the guidance and leadership of Dr. Amir Hanna, the NCHRP program officer, as well as the detailed reviews of the technical review panel that improved the content of the deliverables of this project.

References