Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 64

PREPARING FOR THE UNEXPECTED IN NEW YORK STATE: DEVELOPMENT OF AN EARTHQUAKE RESPONSE PLAN TO ASSESS POTENTIAL BRIDGE DAMAGE

Jerome S. O'Connor, P.E.[1] and Sreenivas Alampalli, Ph.D., P.E.[2]

ABSTRACT

Recent natural extreme events have heightened awareness of the vulnerability of highway infrastructure. Thus, even though New York State is one of the regions with low to moderate seismic activity, realizing that bridge infrastructure may be severely impacted if NYS experiences a low probability medium to severe intensity earthquake, the NYS Department of Transportation (NYSDOT) is developing an earthquake response plan for managing bridge inspections in the aftermath of such an event. This paper will give a brief synopsis of the guidelines under development. It is anticipated that regional NYSDOT engineers will rely on USGS Earthquake Notification System (ENS) for earthquake notifications when their area experiences an earthquake of a magnitude equal to or greater than M3.5. The Earthquake Response Plan calls for an immediate preliminary bridge damage assessment along priority routes to determine if they are safe for use. Subsequent special post-earthquake bridge inspections, conducted by professional engineers, will be prioritized based on their proximity to the epicenter, criticality of the structure, seismic vulnerability of its details, and consequence of failure. The planned level of response will be in proportion to the severity of ground shaking by using a larger radius of concern, level of effort, and the number of bridges to be inspected for increasingly stronger earthquakes.

Keywords: post-seismic inspection, inspection guidelines, inspection prioritization, post-earthquake; bridge inspection; seismic vulnerability.

[1] Senior Program Officer, Transportation Research, MCEER, University at Buffalo, Buffalo, NY 14261, U.S.A.

[2] Director, Bridge Evaluation Services Bureau, New York State Department of Transportation, 50 Wolf Road, Albany, NY 12232, U.S.A.

Introduction

For a long time, NY, and many other states where the probability of earthquakes and the magnitudes associated with them were low, did not design their bridges specifically for seismic loads. (In most cases, seismic loading does not control the bridge design in these states.) Even in California, it wasn't until the 1970's that modern earthquake engineering principles were applied. Since the average highway bridge in the US is 43 years old (45 yrs for NYS highway bridges), many of these structures may not meet current seismic design standards. In addition, over the course of a bridge's service life, corrosion and fatigue may have reduced its capacity to resist loads, especially lateral loads so often associated with seismic events.

Earthquake History in NYS

Although earthquakes that occurred in NYS are rare enough that current residents may only remember one or two mild ones, stronger earthquakes have indeed occurred in the past. In 1884, New York City (NYC) saw a M5.5 earthquake; damage was slight, possibly because the city was not built up as it is today. According to USGS, 16 seismic events were recorded in New York State between 1974 and 2003 with a magnitude ≥ 3.5 (USGS, 2009).

A damaging earthquake could have a severe impact on the safety and functionality of the highway system. The NYC metropolitan area is a particular area of concern, as noted by the New York City Area Consortium for Earthquake Loss Mitigation -- "although NYC is a region with *low seismic hazard* (infrequent damaging earthquakes), it actually has *high seismic risk* because of its tremendous assets, concentration of buildings, and the fragility of its structures, most of which haven't been seismically designed." (NYCEM, 2003). Furthermore, bridges, the most vulnerable component of the highway system, are essential for efficient emergency response and after-event recovery.

Bridge Safety Assurance

About 20 years ago, NYSDOT established a pro-active Bridge Safety Assurance (BSA) program to classify and rank its bridges based on a study of risk analysis. The potential failure modes considered, based on this analysis, include overload, collision, scour, steel details, concrete details, and earthquakes The BSA Program's vulnerability ratings supplement the inspection program's condition ratings to provide a better measure of a bridge's degree of risk (potential for failure and the consequence). This information is used to mitigate risk by making programming prioritizations and resource allocations during bridge management activities.

While the BSA Program helps improve the resiliency of NY's highway network, it is still necessary to be prepared for extreme events due to the potential consequences associated with them. Since NY, like most other states, has lost most structures to scour than any other hazard, it has already implemented policies and procedures specifically for flooding. The Bridge Flood Warning Action Plan (NYSDOT-BFWAP 1995) directs staff on how to react and respond to widespread flooding. The plan described in this paper is under development to complement the BFWAP by providing hazard-specific guidance for the earthquake scenario.

Earthquake Response Plan

The primary objective of the Earthquake Response Plan (ERP) is to provide a timely safety and damage assessment of bridges so that appropriate actions can be prioritized and implemented to protect the traveling public. If damage has occurred, action may include immediate closure, restriction of traffic to emergency vehicles, flagging for repair, detailed investigation, or analysis. Figure 1 provides an overview of the process under development.

NYS is divided into eleven regions for NYSDOT transportation management and administration purposes. Each region is subdivided into residencies. Resident Engineers (RE) are in charge of most of the operational issues in their residency while Regional Structures Engineers (RSE) or Regional Bridge Management Engineers are responsible for bridge related inspection, design, and other activities in their regions. Under the ERP, the RE and the RSE in the affected area will be responsible for executing the plan. In the case of a widespread event that affects multiple DOT regions or results in immediate reports of damage, or if the magnitude is M5.5 or above, the plan recommends that the state's Incident Command System (ICS) be activated to provide an orderly and well coordinated response.

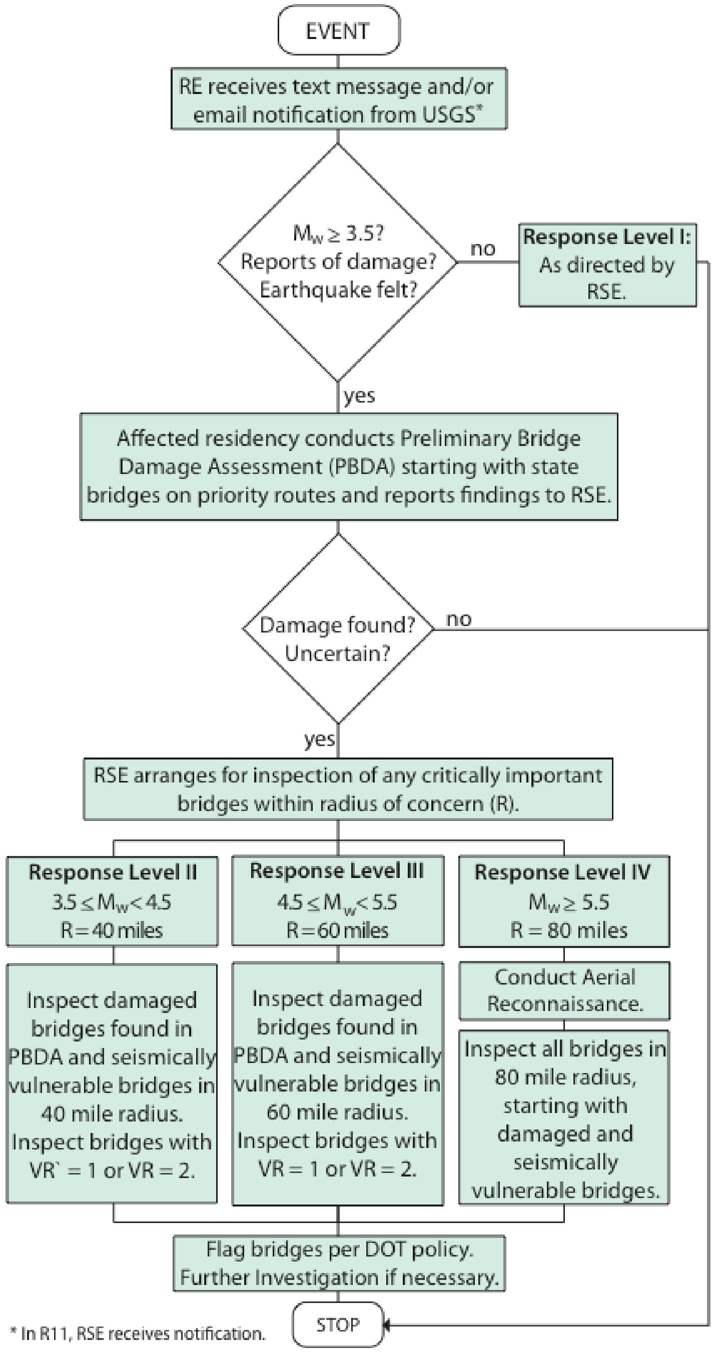


Figure 1: Proposed Process Flowchart for Post-Earthquake Damage Assessment Program

Earthquake Notification Service (ENS)

It is anticipated that implementation of the response plan will be triggered by an electronic alert from the Earthquake Notification Service (ENS) provided by USGS. The ENS message, usually received within 30 minutes of an event, will contain the earthquake magnitude (M) and the coordinates of the epicenter. By subscribing to Eastern US notifications above a certain magnitude level, DOT managers can receive an e-mail and/or cell phone text message soon after such an event occurs. At this time, ENS is available without charge to any person who subscribes at www.usgs.gov. Although earthquake intensity (i.e. the effect that is felt) would be more meaningful than the magnitude (i.e. energy released), this information is not as easily quantified or readily available. In the absence of an ENS, if an earthquake is felt, reports of shaking received from the public, or an earthquake with an epicenter outside of NYS causes shaking within the state, judgment will be applied on which response level to apply. In any case, the Department reserves the option to ratchet up the intensity of investigation if initial findings merit.

Tiered Response

Since the post-seismic response should depend on the severity of the seismic event, four categories have been suggested, the lowest being a discretionary response for minor earthquakes (Response Level I). Since these unnoticed small earthquakes regularly occur and usually cause no damage, a threshold level has been set at M 3.5, below which the extent of investigation will be determined by RSE. During subsequent regular bridge inspections, inspectors will watch for damage that may have been caused by seismic forces.

Response Levels II - IV have been developed such that a higher magnitude earthquake will initiate a more intensive response and a wider area of investigation (i.e., radius of concern). A higher response level also entails a broader scope for bridge inspections. At the highest level, every bridge within the radius of concern will be inspected as soon as possible in a prioritized fashion. The radius of concern for a given magnitude is a general guideline for the geographic region around the epicenter where NYSDOT will focus initial efforts in investigating possible bridge damage. This is intended to be increased if damage is reported to have occurred beyond the limits of the predefined radius.

Preliminary Bridge Damage Assessment (PBDA)

If M ≥ 3.5, investigation will begin in the residency where the epicenter is or where the earthquake was felt. An initial response will be conducted by the RE's operational staff since they can be deployed most quickly. They will conduct an initial reconnaissance by driving the routes in their jurisdiction, giving priority to the most critical routes (as previously defined by their RE). If a damaged bridge is discovered, they will take appropriate actions to close it immediately. The purpose of this phase is to quickly assess the extent of damage so that NYSDOT can execute an appropriate response while informing the public of possible closures and other relevant information. Thus, this initial phase of the Department's ERP can be summarized as Preliminary Bridge Damage Assessment (PBDA).

The primary aim of the PBDA phase is to provide a rapid assessment of structures on priority state routes to ensure that they are safe and functional and to identify any damaged structures that need a more detailed bridge inspection by a professional engineer. This reconnaissance survey will begin with the primary routes on state-owned roads followed by lesser priority state and local roads. These rapid investigations are intended to be conducted by NYSDOT operations staff familiar with the residency's roadways. They will be trained to observe unusual conditions that might have been caused by the earthquake, typically by walking the length of the bridge. The overall status will be reported on one line of a form (see Figure 2).

Preliminary Bridge Damage Assessment (PBDA) Form — NYSDOT

Region 5
County Erie
Date 3/14/09

Team Members: D. Smith, T. Jones

BIN	Feature Carried	Feature Crossed	Arrival Time	Changed condition: Respond 'Yes' or 'No' — Span Collapse? Partial Collapse? Closed or Needs to be Closed?	1. Approach Settlement, cracking	2. Superstructure Damage Girders, expansion joints, deck	3. Substructure Damage Damaged or tipped columns, cracked pier cap, abutments	4. Bearing Damage Displaced, damaged	5. Soil Problems Sloughing, fissure, differential settlement, liquefaction	6. Secondary Systems Wingwalls, bridge railing, utilities	Other Observations	Does an engineer need to look at it?
1006550	I-190	Arthur St.	10:56 A	NO	YES	YES	NO	YES	YES	NO		YES

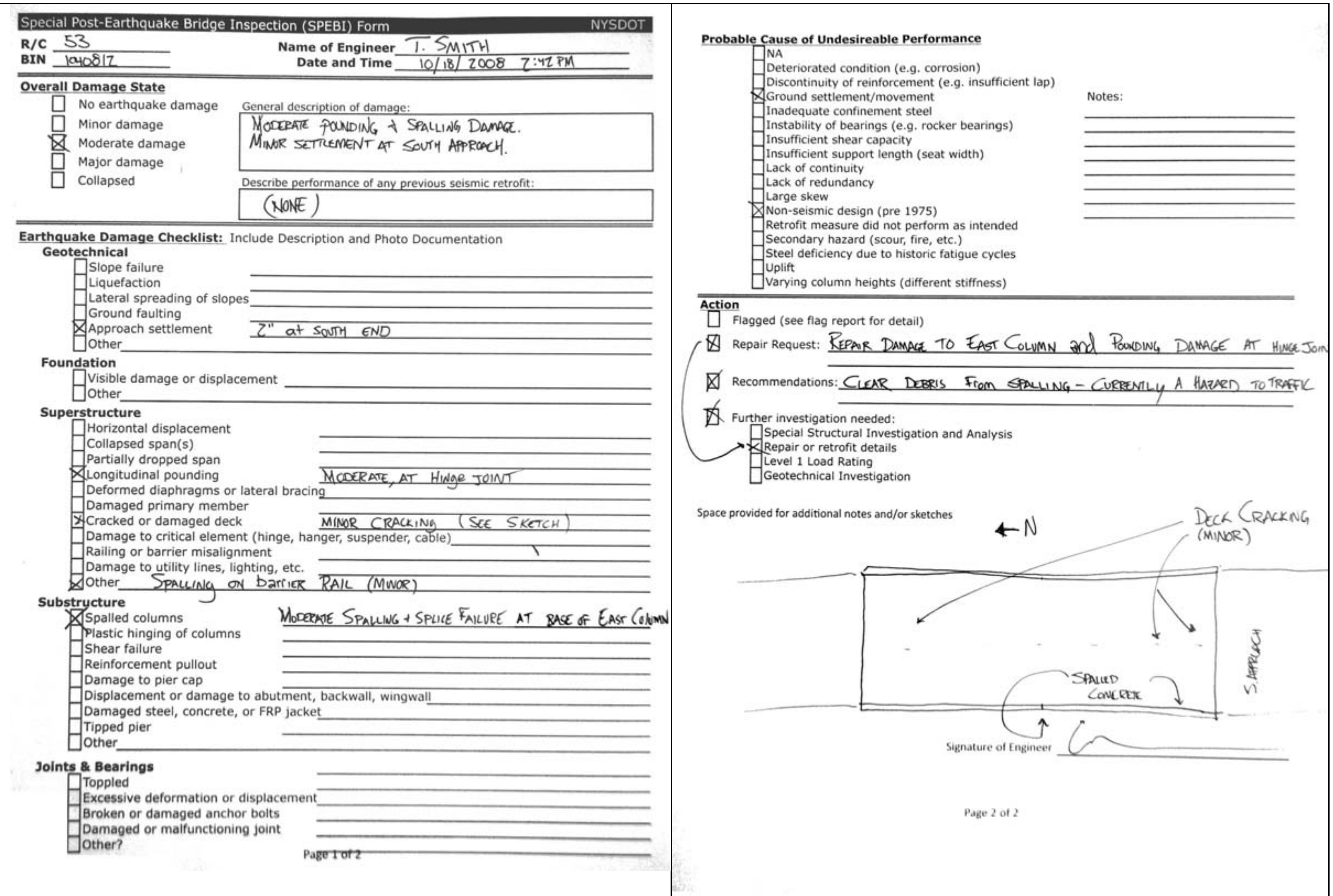
Figure 2. Sample Suggested Preliminary Bridge Damage Assessment Form

Special Post-Earthquake Bridge Inspection (SPEBI)

Special Post-Earthquake Bridge Inspections (SPEBI) are the second phase of damage assessment. They will be conducted by qualified bridge inspection personnel dispatched by the RSE. Team leader of the inspection team will be a professional engineer licensed to practice in New York State with appropriate bridge related experience and training. SPEBI are prioritized using information collected from the route reconnaissance, but also based on bridge criticality and seismic vulnerability. When available, seismic vulnerability ratings (VR) produced under the Department's BSA Program can be used. Each SPEBI results in a detailed multiple page report with photographs of any damage (see Figure 3). These reports will be used for follow-up action, as recommended by the RSE. Table 1 highlights the differences between the PBDAs and the SPEBIs.

Table 1: Two Types of Damage Assessment

Type	**Preliminary Bridge Damage Assessment (PBDA)**	**Special Post-Earthquake Bridge Inspection (SPEBI)**
Objective	Route reconnaissance	Detailed structural and geotechnical inspection of seismically sensitive features and details
Scope	All bridges in affected area, starting with priority routes	Varies according to earthquake magnitude. See flowchart, Figure 1
Access	Drive-through with quick stop at each bridge	Bridge inspection vans & special access equipment if needed
Personnel	Operational staff from a Residency	A professional engineer and supporting bridge inspection team
Timeframe	Immediate (within hours of the event)	Start as soon as possible and continue as necessary
Outcome	▪ Determination of the extent of damage (severity of damage encountered and range from epicenter) ▪ Identification of impassible routes & traffic bottlenecks ▪ Closure of collapsed or dangerous bridges ▪ Recommendations for SPEBI's of damaged bridges	▪ Documentation of critical findings as per the inspection guidelines ▪ Closure of unsafe bridges with structural and/or safety issues ▪ Reopening of bridges that were closed during PBDA, if it is determined that they are safe ▪ Recommendations for further investigation, if warranted ▪ Repair requests
Deliverable	PBDA Form (findings, with one line per bridge)	▪ SPEBI Report for each bridge ▪ Daily Summary Report of bridges inspected



Special Post-Earthquake Bridge Inspection (SPEBI) Form NYSDOT

R/C 53
BIN 1040817
Name of Engineer T. SMITH
Date and Time 10/18/2008 7:42 PM

Overall Damage State
☐ No earthquake damage
☐ Minor damage
☒ Moderate damage
☐ Major damage
☐ Collapsed

General description of damage: MODERATE POUNDING & SPALLING DAMAGE. MINOR SETTLEMENT AT SOUTH APPROACH.

Describe performance of any previous seismic retrofit: (NONE)

Earthquake Damage Checklist: Include Description and Photo Documentation

Geotechnical
☐ Slope failure
☐ Liquefaction
☐ Lateral spreading of slopes
☐ Ground faulting
☒ Approach settlement 2" at SOUTH END
☐ Other

Foundation
☐ Visible damage or displacement
☐ Other

Superstructure
☐ Horizontal displacement
☐ Collapsed span(s)
☐ Partially dropped span
☒ Longitudinal pounding MODERATE, AT HINGE JOINT
☐ Deformed diaphragms or lateral bracing
☐ Damaged primary member
☒ Cracked or damaged deck MINOR CRACKING (SEE SKETCH)
☐ Damage to critical element (hinge, hanger, suspender, cable)
☐ Railing or barrier misalignment
☐ Damage to utility lines, lighting, etc.
☒ Other SPALLING ON BARRIER RAIL (MINOR)

Substructure
☒ Spalled columns MODERATE SPALLING + SPLICE FAILURE AT BASE OF EAST COLUMN
☐ Plastic hinging of columns
☐ Shear failure
☐ Reinforcement pullout
☐ Damage to pier cap
☐ Displacement or damage to abutment, backwall, wingwall
☐ Damaged steel, concrete, or FRP jacket
☐ Tipped pier
☐ Other

Joints & Bearings
☐ Toppled
☐ Excessive deformation or displacement
☐ Broken or damaged anchor bolts
☐ Damaged or malfunctioning joint
☐ Other?

Page 1 of 2

Probable Cause of Undesireable Performance
☐ NA
☐ Deteriorated condition (e.g. corrosion)
☐ Discontinuity of reinforcement (e.g. insufficient lap)
☒ Ground settlement/movement
☐ Inadequate confinement steel
☐ Instability of bearings (e.g. rocker bearings)
☐ Insufficient shear capacity
☐ Insufficient support length (seat width)
☐ Lack of continuity
☐ Lack of redundancy
☐ Large skew
☒ Non-seismic design (pre 1975)
☐ Retrofit measure did not perform as intended
☐ Secondary hazard (scour, fire, etc.)
☐ Steel deficiency due to historic fatigue cycles
☐ Uplift
☐ Varying column heights (different stiffness)

Notes:

Action
☐ Flagged (see flag report for detail)
☒ Repair Request: REPAIR DAMAGE TO EAST COLUMN and POUNDING DAMAGE AT HINGE JOIN
☒ Recommendations: CLEAR DEBRIS FROM SPALLING – CURRENTLY A HAZARD TO TRAFFIC
☒̸ Further investigation needed:
☐ Special Structural Investigation and Analysis
☒ Repair or retrofit details
☐ Level 1 Load Rating
☐ Geotechnical Investigation

Space provided for additional notes and/or sketches

Signature of Engineer

Page 2 of 2

SPEBI form, sheet 1 of 2	SPEBI form, sheet 2 of 2

Figure 3. Sample Suggested Form for Special Post-Earthquake Bridge Inspections

Responsibilities

In all cases, the Resident Engineers and the Regional Structures Engineers in the affected area will be the managers responsible for executing the plan, working with other groups and management. The RE will be responsible for conducting an initial assessment of damage within hours of the event. The RSE will use that information along with seismic vulnerability data to schedule more detailed inspections. The RSE will coordinate follow-up action such as response to critical findings and remedial work. The RE and RSE will work in their respective areas of expertise, coordinating their efforts for a coherent overall effort. Obviously, the higher the earthquake magnitude, the more resources will be needed in order to obtain a good understanding of the problem in a reasonable amount of time.

These response levels have been suggested using the best information available when this plan was developed. Since the effect of an earthquake depends on several factors, the recommended magnitude ranges are considered approximate. After an earthquake, initial reports and inspection findings can be used for elevating the response level. The RSE will be tasked with making this judgment working with other technical experts as well as incident reports. A higher response level will be used if damage is more extensive than anticipated or if it allows a quicker and more thorough determination of bridge damage.

Conclusions

New York State is one of the regions with low to moderate seismic activity. Even though the likelihood of a damaging earthquake is remote, consequences could be severe, especially in urban areas. Realizing that there is value in having an earthquake response plan in place to mitigate risk, the NYSDOT is developing an earthquake response plan for managing bridge inspections in the aftermath of such an event. In the absence of nationally accepted standards for post-earthquake bridge inspection procedures, NYSDOT initiated a research project to develop the guidelines that are under development and are briefly described in this paper. Though this procedure is tailored to NYSDOT needs, it may be useful to other highway transportation agencies with necessary modifications. Key provisions of this plan include:

(1) A carefully constructed ERP that will allow for a quick assessment of system safety and functionality, followed by progressively comprehensive damage assessments that consume resources at a level that is proportional to the severity of the event.
(2) Clear lines of responsibility that will help to avoid confusion. The state's ICS can be used in any emergency situation but precautionary measures taken for lesser events will be handled regionally by Department managers.
(3) Forms and detailed procedures to facilitate post-earthquake damage assessments.

Also under development are a) an inspection manual with photographs of bridges that illustrate the types of earthquake damage that might be encountered, b) a training module geared towards professional engineers who do not routinely inspect bridges that may have to conduct post-seismic inspections and c) an algorithm/database for prioritization of bridges requiring inspection.

Acknowledgements

Financial support for the development of post-earthquake bridge inspection procedures was provided by the New York State Department of Transportation through the Transportation Infrastructure Research Consortium (TIRC) at Cornell University. The views presented in this paper represent those of the authors and not necessarily of the agencies represented by the authors and sponsoring agencies.

References

(NYCEC, 2003). *Earthquake Risks and Mitigation in New York State*, The New York City Area Consortium for Earthquake Loss Mitigation, MCEER-03-SP02, University at Buffalo, Buffalo, NY

(NYSDOT-BFWAP, 2005). *Bridge Flood Warning Action Plan for State Bridges*, URL: https://www.nysdot.gov/divisions/engineering/structures/repository/files/ BFWAP95.pdf, New York State Department of Transportation, Albany, NY

(NYSDOT-BSA, 1995). "*Bridge Safety Assurance Seismic Vulnerability Manual*", New York State Department of Transportation Structures Design and Construction Division (1995), Albany, NY

(USGS, 2009) URL accessed: http://earthquake.usgs.gov/regional/states/top_states.php