# RISK AND RESILIENCE OF BRIDGES: TOWARD DEVELOPMENT OF HAZARD-BASED ASSESSMENT FRAMEWORK, RESEARCH NEEDS, AND BENEFITS OF ACCELERATED CONSTRUCTION

**Quarterly Progress Report**
**For the period ending August 31, 2021**


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ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
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Miami, FL

# 1. Background and Introduction

Transportation networks are modeled in the form of links and nodes. Links represent the highways, while the nodes represent bridges connecting the highways which act as hubs for several links. Closure of a single bridge within the transportation network can lead to substantial disruptions to the entire network and the communities it serves. For example, the local damage of the I-65 North overpass bridge in Alabama in January 2002 (due to accidental explosion of truck) caused a traffic interruption for almost 50 days. Assessment of risk and resilience of existing bridges and new bridges, including ABC bridges, accelerated upgrade, and accelerated repair is important to devise appropriate pre-hazard preparedness plans and post-hazard mitigation response strategies and recovery time. This joint project seeks to document and synthesize the current state of practice related to assessment of risk and resilience of bridges and other structures and to conduct target surveys to identify the current practices within transportation agencies and cities. The collected information will be utilized to develop a holistic resilience and risk assessment framework for existing and new bridges, including ABC bridges, accelerated upgrade (enhanced robustness), and accelerated repair (enhanced rapidity), under multi-hazards to emphasize on the benefits of accelerated construction and repair. Finally, this project will develop a specific resilience framework for seismic hazards. The success of this project will promote ABC nationwide to stakeholders as one of the most suited construction methods for resilient bridges and transportation infrastructures.

# 2. Problem Statement

Assessment of resilience of roadway bridges due to natural and man-made hazards is an important element of economic and societal vulnerability and safety because the closure of a single bridge within a transportation network can cause major disruptions to the entire network and the communities it serves. Also, the assessment of risk and resilience of individual bridge components as well as bridge systems is important to devise pre-hazard preparedness plans and post-hazard mitigation response strategies and recovery time. Recent developments in informed decision-making including risk and decision analysis, risk analytics, risk science and decision support standards are excellent tools for quantifying benefits of accelerated bridge construction. In addition to including risk and resilience with respect to structural performance under natural and man-made hazards, such tools allow for integration of stakeholders' perception and policy toward accelerated construction, maintenance, and rehabilitation, thereby promoting ABC to stakeholders. Currently, assessment of risk and resilience of roadway bridges is either performed qualitatively by expert judgments or quantitatively by statistical analyses and other tools depending upon the available data. The purpose of this multi-institutional and multidisciplinary project is to develop a framework for hazard-based assessment, research needs, and benefits of accelerated construction. One of the unique aspects of the proposed framework is integration of stakeholders' perception and policy toward accelerated construction using the recent developments in social and risk sciences. The proposed framework will address risk and resilience of both existing and new

bridges, with a priority on ABC bridge systems, to highlight the benefit of accelerated construction. Both natural and man-made hazards will be considered.

# 3. Objectives and Research Approach

The main objectives of this project are:

- Documenting the current state of practice related to assessment of risk and resilience of bridges nationally and internationally.
- Synthesizing the state of practice related to assessment of risk and resilience of other structures against man-made and natural hazards with the goal of identifying frameworks and assessment tools that can be readily adopted for bridges.
- Conducting target online surveys of state DOTs and cities to evaluate the practice of existing bridge performance tools.
- Developing a holistic resilience and risk assessment framework for existing and new bridges, including ABC bridges (accelerated upgrade, and accelerated repair), under multi-hazards to emphasis on accelerated construction benefits.
- Developing a specific resilience framework for seismic hazard as an example of natural hazards.

Regarding the approach, the adopted methodology is known as the 4R-Methodology and it will be further expanded to 5R-Methodology, considering a new dimension, Regional Societal impact, which will help quantify economic and social impacts. The 5R-methodology includes the following:

- **Robustness:** the ability to withstand a hazard with little or no loss of functionality.
- **Rapidity:** the recovery time which is needed for the system functionality or target functionality to be recovered.
- **Redundancy:** components that keep the systems functionality even after the loss of part of the system.
- **Resourcefulness:** the ability to mobilize resources after the hazard.
- **Regional societal impact:** economic and social impact including safety and mobility.

# 4. Description of Research Project Tasks

The following is a description of tasks carried out to date.

### Task 1 – Conducting a literature review on risk and resilience of roadway bridges under natural and man-made hazards

In this task, the existing guidelines and protocols used by state and federal DOTs and cities for the assessment of risk and resilience of roadway bridges due to natural and man-made hazards are

documented. The literature focused on the guidelines and protocols available nationally and internationally is being collected, reviewed, synthesized, and documented. It is expected that the existing methodologies for the assessment of risk and resilience of buildings and other structures will aid in the development of the framework for risk and resilience of bridges due to natural and man-made hazards

For the assessment of risk and resilience of roadway bridges:

- The existing guidelines and protocols used by state and federal DOTs and cities due to natural and man-made hazards are documented.
- Guidelines and protocols available nationally and internationally are collected, reviewed, synthesized, and documented.
- The state-of-the art in resilience assessment for natural and man-made hazards is documented.
- Description of work performed up to this period: **30%**

During the second quarter 17 additional sources have been added, resulting in a total of 60 resources 60. The categorization in Figure 1 identifies the areas that need additional sources. Also, Figure 1 shows the distribution of the information gathered and reviewed to date, so far.

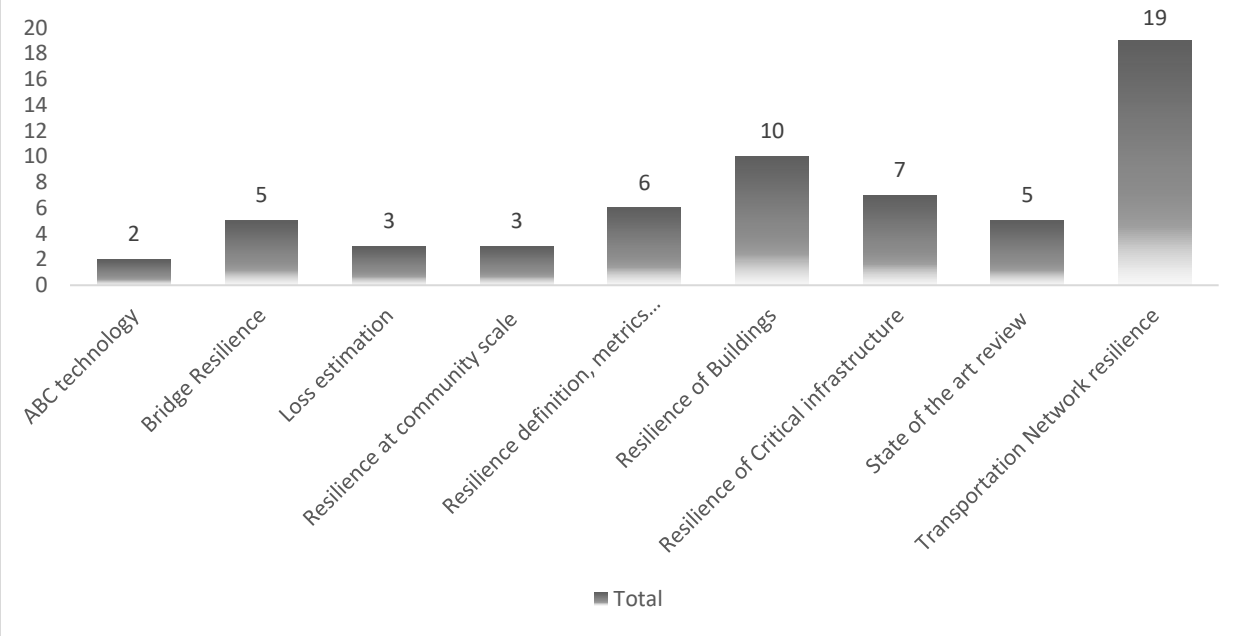



Figure 1: Number of sources in each Category

Until the end of the second quarter, 25 summaries of the most relevant documents have been prepared for integration into a final report and subsequential publication.

A combined list of all documents (papers, reports, and other materials) is included in Appendix 1. The new documents (No. 50 to No. 66) added during the reporting period are highlighted in blue.

This appendix also includes full reference of each document including authors, category, and subcategories.

The categories and subcategories considered are listed in Table 1. The subcategories describe the content of the documents briefly.

Table 1: Categories and Subcategories of Articles Collected in the Literature Search

| Row Labels |
|---|
| **ABC technology** |
| ABC Toolkit for design recommendations |
| Implementations of methods to be used ABC Manual |
| **Bridge Resilience** |
| Fragility analysis for Retrofit Bridges |
| Functionality of bridge |
| Functionality-Fragility Surface: Fragility Curves and Restoration Functions |
| Guidelines for Seismic Performance Assessment of Bridges |
| Seismic fragility curves for Bridges |
| **Loss estimation** |
| earthquake loss estimation methods of the HAZUS technology |
| Loss estimation: FEMA and Hazus-HM Applied to bridges |
| Loss estimation: FEMA P-58 applied to region |
| **Resilience at community scale** |
| Multi-hazard PEOPLES Resilience |
| Seismic Resilience of Communities |
| **Resilience definition, metrics and evaluation** |
| Concepts and measurement of resilience |
| Definition, Metrics, and Valuation for Decision Making |
| Measurement Frameworks and Metrics |
| Method for evaluation Comparing resilience |
| Resilience Metrics and case study |
| Seismic resilience in chapter 11 |
| **Resilience of Buildings** |
| Expected Seismic Performance of Code |
| Guidelines for Seismic Design of Buildings |
| implementation Guide |
| Methodology |
| Methodology for Assessing Environmental Impacts |
| Methodology supporting materials |
| Organizational Resilience, Building Resilience, and Ambient Resilience |
| Recommendation for seismic evaluation |
| resilience-based earthquake design for new buildings |
| Tools for Seismic Design and Assessment |
| **Resilience of Critical infrastructure** |

| |
|---|
| Comparison of Network resilience |
| Manmade Hazard: application to blast risk assessment |
| Probabilistic Resilience Infrastructure |
| Resilience management ISO 31000 Risk Management |
| Resilience of lifelines: Seismic Hazard |
| Societal Resilience |
| Theorical Classification of vulnerability |
| **State of the art review** |
| Disaster resilience individual and regional |
| Emergency Reconstruction Of Critical infrastructure |
| Highway Bridges for Regional Risk and Resilience Assessment |
| Interdisciplinary Resilience International |
| Transportation asset resilience |
| **Transportation Network resilience** |
| Comparison of Network resilience |
| Congestion Prediction Application of big Data |
| Consumer surplus economic impact studies |
| Cost-Based Postdisaster Intervention |
| empirical GPS data |
| Flow capacity of bridges Network Resilience |
| fragility analysis and traffic flow distribution under extreme events |
| framework for measures of resilience |
| framework for resilience in transportation system |
| Hazard-Induced Bridge Damages |
| Integrating risk and resilience to Catastrophe management |
| Intensity maps for seismic hazard |
| optimal retrofit |
| potential gaps and opportunities |
| Resilience and Sustainability |
| Resilience assessment framework |
| Seismic Evaluation of bridge portfolio using machine learning |
| Seismic Resilience + aging transportation network |
| **Grand Total = 60 sources** |

**Task 2 – Conducting a target online survey of state DOTs and cities to evaluate the current practice and efficacy of existing bridge performance assessment tools**

In this task, a targeted survey of state DOTs and cities is being conducted to evaluate the current practice and efficacy of existing bridge performance assessment tools. The survey questionnaire is expected to capture agency preparedness and protocols for handling risk and resilience of bridges. The survey questionnaire is being developed with assistance from the ABC-UTC Advisory Committee, which includes representatives from state DOTs, AASHTO, FHWA and industry. In addition to providing useful information on risk and resilience framework, the survey is seeking to identify topics and priorities for future research. Once the questionnaire is fully developed, the survey will be conducted using an online platform. It is expected to take about 15 minutes to complete the survey. This shorter timeline is expected to increase participation and not to overwhelm participants (OU to lead this effort with assistance from the FIU and UNR teams). In this survey, collaboration with the University of Oklahoma Decision Analytics Lab (DAL) is playing a key role in addressing the social dimension of awareness, perception, and benefits of ABC. The research team is working with the ABC-UTC leadership to identify stakeholders. The Co-PI, Dr. Cokely and his team from DAL are experienced in social surveys and are equipped with the analysis tools. The survey results are expected to have broad benefits for ABC-UTC, including and beyond the scope of this project. In some cases, strategically-designed interviews with specific professionals are being conducted to obtain more information related to the current practice and efficacy of existing bridge performance assessment tools.

Description of work performed up to this period: **50%**

Two surveys were prepared during the second quarter (Survey 1 and Survey 2 as mentioned hereinafter).

*Survey 1: Existing tools and current practices:* This survey focuses on the assessment of resilience tools, protocols, and perception of available tools. The goals of this survey are:

- To provide useful information on risk and resilience framework;
- To capture protocol handling risk and resilience of bridges; and
- To identify topics and priorities for future research.

*Survey 2: Social perception:* This survey focuses on the assessment of the perception, awareness, and benefits of ABC in terms of social, economic, delivery time, environmental impact, costs and social impacts. The objectives of this survey are:

- To gain an insight of social awareness, perception, and benefits of ABC; and
- To identify stakeholders.

A draft of both of these surveys is included in Appendix 2. For assistance with the questionnaire, personal interviews are being conducted with domain experts. One of the goals of these interviews is to develop an objective list of choices for a given question or item. It is expected that this process will reduce the time of the survey significantly. During the reporting period, one interview was

conducted with an individual from the Bridge Division, Oklahoma Department of Transportation. Details of this survey will be reported in the next quarterly report along with additional interviews the team plans to conduct during the next quarter.

As a follow-up to this survey, the OU team is reviewing the long-term bridge performance (LTBP) database maintained by FHWA. As part of this program, information is collected periodically and added to the database. This database contains bridge data from across the country and is readily accessible. The LTBP program is a long-term research effort, authorized by the U.S. Congress with the purpose of collecting high-quality data from representative highway bridges nationwide (Figure 2).

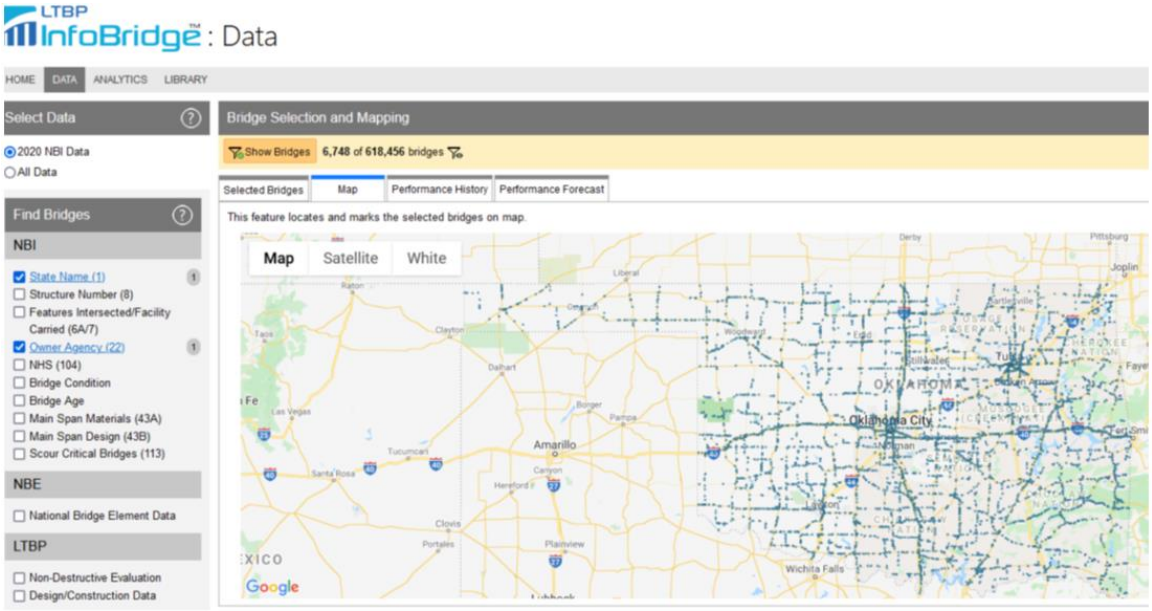



Figure 2: Info Bridge web page.

**Task 3- Development of holistic resilience and risk assessment framework of existing and new bridges under multi-hazards to emphasis on accelerated construction benefits**

In this task, the results from the abovementioned efforts will be utilized to develop a holistic resilience and risk assessment framework for existing and new bridges and the benefits of accelerated repair methods (enhanced rapidity) and accelerated upgrade methods (enhanced robustness). The framework will be developed in a generic form for different natural and manmade hazards. The resilience will be quantified using a modified 5R-methodology described hereinbefore. These quantities will be used to develop resilience loss indicators ($I_R$)

Description of work performed up to this period: No progress to report at this period

**Task 4- Development of a specific resilience framework**

In this task, specific resilience framework will be developed for assessing the seismic resilience

of existing bridges and ABC bridge candidates such as those with self-centering capabilities. The framework will include the benefit of accelerated upgrade before the event and accelerated repair after the event on the resilience of existing bridges

Description of work performed up to this period: No progress to report for this period

**Task 5- Final Report.**

In this Task, full assessment of the findings from Task 1 through Task 4 will be conducted and a report will be published on risk and resilience assessment of existing and new ABC bridge systems. The benefit from accelerated upgrade prior to an event and accelerated repair after an event will be emphasized to promote ABC to shareholders.

Description of work performed up to this period: No progress to report at this period

# 5. Expected Results and Specific Deliverables

- Documented state of practice related to assessment of risk and resilience of bridges nationally and internationally.
- Documented state of practice related to assessment of risk and resilience of other structures against man-made and natural hazards.
- Survey of state DOTs and cities: **Survey of existing tools and current practices**
- Survey of state DOTs and cities: **Survey of stakeholders**
- Developed holistic resilience and risk assessment framework for existing and new bridges, including ABC bridges with an emphasis on accelerated construction benefits.
- Developed specific resilience framework for seismic hazard as an example of natural hazards.
- Final Report

# 6. Schedule

Progress of tasks in this project is shown in the table below. The total amount of work done reported herein is an estimate made according to the time spent and the total time for each task. The literature review is considered an ongoing activity throughout this project.

| Item | % Completed |
|---|---|
| Percentage of Completion of this project to Date | **34%** |

| Research Tasks | 2021 | | | | | | | | | | | | 2022 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J |
| **Task 1 –** Conducting a literature review on risk and resilience of roadway bridges under natural and man-made hazards. | 30% | | | | | | | | 70% | | | | | | | | | |
| **Task 2 –** Conducting a target survey for state DOTs and cities using online survey service to evaluate the current practice and existing bridge performance assessment tools. | | | | 50% | | | | | 50% | | | | | | | | | |
| **Survey 1 - Survey of existing tools and current practices** | | | | 50% | | | | | | | | | | | | | | |
| **Subtask 1 -** Review of Literature | | | | | | | | | | | | | | | | | | |
| **Subtask 3 -** Definition of objectives and scope | | | | | | | | | | | | | | | | | | |
| **Subtask 4** - Elaboration of Survey | | | | | | | | | | | | | | | | | | |
| **Subtask 5** - Execution of survey | | | | | | | | | | | | | | | | | | |
| **Subtask 6** - Analysis of information obtained | | | | | | | | | | | | | | | | | | |
| **Survey 1 - Survey of Stakeholders** | | | | 50% | | | | | | | | | | | | | | |
| **Subtask 1 -** Review of Literature | | | | | | | | | | | | | | | | | | |
| **Subtask 3 -** Definition of objectives and scope | | | | | | | | | | | | | | | | | | |
| **Subtask 4** - Elaboration of Survey | | | | | | | | | | | | | | | | | | |
| **Subtask 5** - Execution of survey | | | | | | | | | | | | | | | | | | |
| **Subtask 6** - Analysis of information obtained | | | | | | | | | | | | | | | | | | |
| **Task 3-** Development of holistic resilience and risk assessment framework of existing and new bridges | | | | 100% | | | | | | | | | | | | | | |
| **Task 4-** Development of a specific resilience framework. | | | | | | | | | | 100% | | | | | | | | |
| **Task 5-** Final Report. | | | | | | | | | | | | | | | | 100% | | |

Work performed

Work to be performed

# 7. References

All references are listed in Appendix 1.

## Appendix 1: List of literature review by category

| Row Labels | Count of Category |
|---|---|
| ABC technology | 2 |
| Bridge Resilience | 5 |
| Loss estimation | 3 |
| Resilience at community scale | 3 |
| Resilience definition, metrics, and evaluation | 6 |
| Resilience of Buildings | 10 |
| Resilience of Critical infrastructure | 7 |
| State of the art review | 5 |
| Transportation Network resilience | 19 |
| **Grand Total** | **60** |

Details of literature collected so far (literature collected during the reporting period highlighted in blue)

| Number | Full Reference | Category | Sub-category |
|---|---|---|---|
| 1 | Seismic Resilience of Transportation Networks with Deteriorating Components | Transportation Network resilience | Seismic Resilience + aging transportation network |
| 2 | The REDI™ rating system: a framework to implement resilience-based earthquake design for new buildings | Resilience of Buildings | resilience-based earthquake design for new buildings |
| 3 | Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making | Resilience definition, metrics and evaluation | Definition, Metrics, and Valuation for Decision Making |
| 4 | A stochastic computational framework for the joint transportation network fragility analysis and traffic flow distribution under extreme events | Transportation Network resilience | fragility analysis and traffic flow distribution under extreme events |
| 6 | Estimation of Earthquake Loss due to Bridge Damage in the St. Louis Metropolitan Area. II: Indirect Losses | Loss estimation | Loss estimation: FEMA and Hazus-HM Applied to bridges |
| 7 | Multiple-Hazard Fragility and Restoration Models of Highway Bridges for Regional Risk and Resilience Assessment in the United States | State of the art review | Highway Bridges for Regional Risk and Resilience Assessment |
| 8 | Emergency Reconstruction of Critical Transportation Infrastructure | State of the art review | Emergency Reconstruction Of Critical infrastructure |
| 9 | Lifelines in earthquakes a case study based on wellington | Resilience of Critical infrastructure | Resilience of lifelines: Seismic Hazard |
| 10 | Post-hazard flow capacity of bridge transportation network considering structural deterioration of bridges | Transportation Network resilience | Flow capacity of bridges Network Resilience |
| 11 | Post-earthquake functionality of highway overpass bridges | Bridge Resilience | Functionality of bridge |
| 12 | Rapid seismic damage evaluation of bridge portfolios using machine learning techniques | Transportation Network resilience | Seismic Evaluation of bridge portfolio using machine learning |
| 15 | Multi-Scale Classification of Ontario Highway Infrastructure: A Network Theoretic Approach to Guide Bridge Rehabilitation Strategy | Resilience of Critical infrastructure | Theorical Classification of vulnerability |
| 16 | Resilience of Regional Transportation Networks Subjected to Hazard-Induced Bridge Damages | Transportation Network resilience | Hazard-Induced Bridge Damages |
| 17 | Predicting Congestion States from Basic Safety Messages by Using Big-Data Graph Analytics | Transportation Network resilience | Congestion Prediction Application of big Data |
| 18 | Functionality-fragility surfaces | Bridge Resilience | Functionality-Fragility Surface: Fragility Curves and Restoration Functions |
| 19 | Resilience-based design of urban centers: application to blast risk assessment | Resilience of Critical infrastructure | Man made Hazard: application to blast risk assessment |
| 20 | Resilience Metrics | Resilience definition, metrics and evaluation | Resilience Metrics and case study |
| 21 | Measurement Frameworks and Metrics for Resilient Networks and Services: Technical report | Resilience definition, metrics and evaluation | Measurement Frameworks and Metrics |
| 22 | Probabilistic Resilience-Guided infrastructure risk Management | Resilience of Critical infrastructure | Probabilistic Resilience Infrastructure |
| 23 | Redi™ Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings | Resilience of Buildings | Organizational Resilience, Building Resilience, and Ambient Resilience |
| 24 | Volume 1 – Methodology Second Edition. Seismic Performance Assessment of Buildings | Resilience of Buildings | Methodology |
| 25 | Volume 2 – Implementation Guide. Seismic Performance Assessment of Buildings | Resilience of Buildings | implementation Guide |
| 26 | Volume1 Methodology supporting materials. Seismic Performance Assessment of Buildings | Resilience of Buildings | Methodology supporting materials |
| 27 | Volume 4 – Methodology for Assessing Environmental Impacts. Seismic Performance Assessment of Buildings | Resilience of Buildings | Methodology for Assessing Environmental Impacts |
| 28 | Volume 5 – Expected Seismic Performance of Code-Conforming Buildings. Seismic Performance Assessment of Buildings | Resilience of Buildings | Expected Seismic Performance of Code |

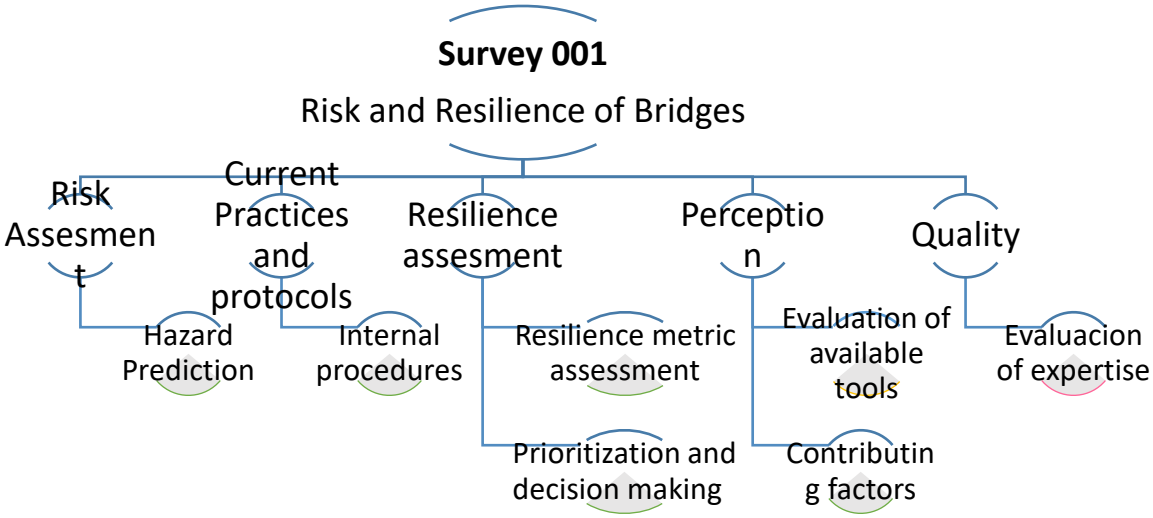
| Number | Full Reference | Category | Sub-category |
|---|---|---|---|
| 29 | Guidelines for Performance-Based Seismic Design of Buildings | Resilience of Buildings | Guidelines for Seismic Design of Buildings |
| 30 | A Guide to State-of-the-Art Tools for Seismic Design and Assessment. Building the Performance, You Need | Resilience of Buildings | Tools for Seismic Design and Assessment |
| 31 | Proposed AASHTO Guidelines for Performance-Based Seismic Bridge Design | Bridge Resilience | Guidelines for Seismic Performance Assessment of Bridges |
| 32 | ABC Manual Experience in design, fabrication and erection of prefabricated bridge elements and systems manual | ABC technology | Implementations of methods to be used ABC Manual |
| 33 | Innovative Bridge Designs for Rapid Renewal ABC Toolkit | ABC technology | ABC Toolkit for design recommendations |
| 35 | Management of Resilience in Civil Infrastructure Systems: An Interdisciplinary Approach | State of the art review | Interdisciplinary Resilience International |
| 36 | Seismic Fragility Methodology for Highway Bridges | Bridge Resilience | Seismic fragility curves for Bridges |
| 37 | Retrofitted Bridge Fragility Analysis for Typical Classes of Multispan Bridges | Bridge Resilience | Fragility analysis for Retrofit Bridges |
| 39 | A Scalable Framework for Assessing Seismic Resilience of Communities | Resilience at community scale | Seismic Resilience of Communities |
| 40 | Resilience Criteria for Seismic Evaluation of Existing Buildings: A Proposal to Supplement ASCE 31 for Intermediate Performance Objectives | Resilience of Buildings | Recommendation for seismic evaluation |
| 41 | Application of the FEMA-P58 methodology for regional earthquake loss prediction | Loss estimation | Loss estimation: FEMA P-58 applied to region |
| 43 | A framework for defining and measuring resilience at the community scale: the people's resilience framework | Resilience at community scale | Multihazard PEOPLES Resilience |
| 44 | A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities | Resilience at community scale | Seismic Resilience of Communities |
| 45 | Comparative Visualization of Predicted Disaster Resilience | Resilience definition, metrics and evaluation | Method for evaluation Comparing resilience |
| 46 | Conceptualizing and Measuring Resilience | Resilience definition, metrics and evaluation | Concepts and measurement of resilience |
| 47 | From Risk Management to Resilience Management in Critical Infrastructure | Resilience of Critical infrastructure | Resilience management ISO 31000 Risk Management |
| 48 | Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience | State of the art review | Transportation asset resilience |
| 49 | ISRA: IMPROVER societal resilience analysis for critical infrastructure | Resilience of Critical infrastructure | Societal Resilience |
| **50** | **Disaster Resilience: A Guide to the Literature** | **State of the art review** | **Disaster resilience individual and regional** |
| **51** | **Effective sampling of spatially correlated intensity maps using hazard quantization Application to seismic events** | **Transportation Network resilience** | **Intensity maps for seismic hazard** |
| **52** | **Metrics and algorithm for optimal retrofit of resilient transportation network** | **Transportation Network resilience** | **optimal retrofit** |
| **53** | **Empirically quantifying city-scale transportation system resilience to extreme event** | **Transportation Network resilience** | **empirical GPS data** |
| **54** | **Transportation sector resilience** | **Transportation Network resilience** | **potential gaps and opportunities** |
| **55** | **Resilience in Transportation Systems** | **Transportation Network resilience** | **framework for resilience in transportation system** |
| **56** | **Integrating Risk and Resilience Approaches to Catastrophe management in engineering systems** | **Transportation Network resilience** | **Integrating risk and resilience to Catastrophe management** |
| **57** | **Measuring the resilience of transport** | **Transportation Network resilience** | **Resilience assessment framework** |

| Number | Full Reference | Category | Sub-category |
|---|---|---|---|
| 58 | Resilience and Sustainability of Civil Infrastructure Toward a Unified Approach. | Transportation Network resilience | Resilience and Sustainability |
| 59 | Optimal Resilience- and Cost-Based Postdisaster Intervention Prioritization for Bridges along a Highway Segment | Transportation Network resilience | Cost-Based Postdisaster Intervention |
| 60 | The Framework for calculating the measure of resilience for intermodal transportation systems | Transportation Network resilience | framework for resilience in transportation system |
| 61 | Incorporating transportation network modeling tools within transportation economic impact studies of disasters | Transportation Network resilience | Consumer surplus economic impact studies |
| 62 | FRAMEWORK OF CALCULATING THE MEASURES OF RESILIENCE (MOR) FOR INTERMODAL TRANSPORTATION SYSTEMS | Transportation Network resilience | framework for measures of resilience |
| 63 | A Comparison of Transportation network resilience under simulated system optimum and user equilibrium conditions | Transportation Network resilience | Comparison of Network resilience |
| 64 | Perspectives On European Earthquake and sismology | Resilience definition, metrics and evaluati | Seismeic resilience in chapter 11 |
| 65 | HAZUS Earthquake Loss Estimation Methods | Loss estimation | earthquake loss estimation methods of the HAZUS technology |
| 66 | Resilience Primer for Transportation Executives | Resilience of Critical infrastructure | Comparison of Network resilience |

## Appendix 2: Draft of Survey 1 and Survey 2

| SURVEY Nº 001- Risk and Resilience of Bridges | |
|---|---|
| Objectives | • Consult about **current practices related to resilience especially for bridge network and role of Accelerated Bridge Construction and Repair**, and<br>• **Perception** of bridge performance assessment tools,<br>• Contributing factors Bridge and Network Resilience.<br>• Capture the agency's **protocols related to bridge and network resilience**.<br>• It is expected that the survey will help identify future opportunities to expand research. |
| Tools | **Mental map Model** |
| Time | **15 minutes** |
| version | **D (Draft)** |
| Date | **08/30/2021** |

**Survey 1: Risk and Resilience of Bridges:** This survey seeks to obtain feedback from state and federal DOTs and other on the current practices related to resilience, bridge performance assessment tools and contributing factors for bridge and network resilience. The areas of interest we have been identified and are given below.




**QUESTIONAIRE**

**Risk Assessment**

<u>What type of specifications and protocols are used for hazard prediction in the agency?</u>
(Give option for types of hazards) select all that apply to your location.

*Hazard prediction for bridge Resiliency*

- What type of hazards does your agency deal with? Please rank the hazards based on their importance to your agency?

  - [ ] Earthquake
  - [ ] Tsunami
  - [ ] Flood
  - [ ] Costal Surge
  - [ ] Hurricanes
  - [ ] other
  - [ ] Explosion
  - [ ] Impact load
  - [ ] Other

  *Please provide a brief explanation.*

- Mention the existing tools and Software for hazard prediction both in severity and frequency?
  *Rank them according to their value and provide a brief explanation of your evaluation*.

- Mention web pages (existing online tools) for hazard maps that your organization utilizes.
  *Rank them according to their value and provide a brief explanation of your evaluation.*

- What are three most important issues or obstacles have you encountered regarding hazard prediction in your agency.
  *Mention and give a brief explanation.*

**Current practices and protocols**

Which departments, within your agency, are in charge of maintaining the bridge inventory and what are their roles?

*Internal procedures*

- Do you consider **structural Resilience** for bridges as a criterion for internal decision making in relation to bridge maintenance and preservation? If, yes.
  Mention the preferred approach.
  Mention the major advantage.
  Mention major challenge.
  Mention another approach used in the agency.

- Do you consider **network Resilience** as a criterion for internal decision making in relation to pre-hazard preparedness and post hazard reconnaissance and recovery? If, yes.
  Mention the preferred approach.
  Mention the major advantage.
  Mention major challenge.
  Mention another approach used in the agency.

- In case of severe events with widespread damage how does your agency manage the **damage evaluation of bridges?**
  Mention the preferred approach.
  Mention the major advantage.
  Mention major challenge.
  Mention another approach used in the agency.

- In case of severe events with widespread damage how does your agency manage the **project execution and recovery**?
  Mentioned the preferred approach.
  Mention the major advantage.

Mention major challenge.
Mention another approach used in the agency.

**Resilience Assessment**

<u>How would you define a resilient structure and network, given your understanding of resilience?</u>

*Resilience metric assessment*

- Do you consider accelerated construction, repair and upgrade techniques in your decision making process during hazard preparedness process and during the recovery process?
  Give a brief explanation

- When assessing the functionality loss of a Bridge structure what is the preferred method and what are the most important factors that contribute to an accurate representation?
  Mentioned the preferred approach
  Mention the most important factors that contribute and provide accurate representation of functionality and functionality loss
- What effect do you consider ABC solutions or techniques have over the resiliency of a bridge?
  Please provide a brief explanation.

- What do you consider to be the most important metrics for resilience?
  Please provide a brief explanation

- How do you incorporate redundancy in bridge design and repair?
  Mentioned the preferred approach.
  Mention the major advantage.
  Mention major challenges.
  Mention another approach used in the agency

- How do you integrate cost in your decision making and budget during planning and after an event?
  Mentioned the preferred approach.
  Mention the major advantage.
  Mention major challenges.
  Mention another approach used in the agency

*Prioritization and decision making*

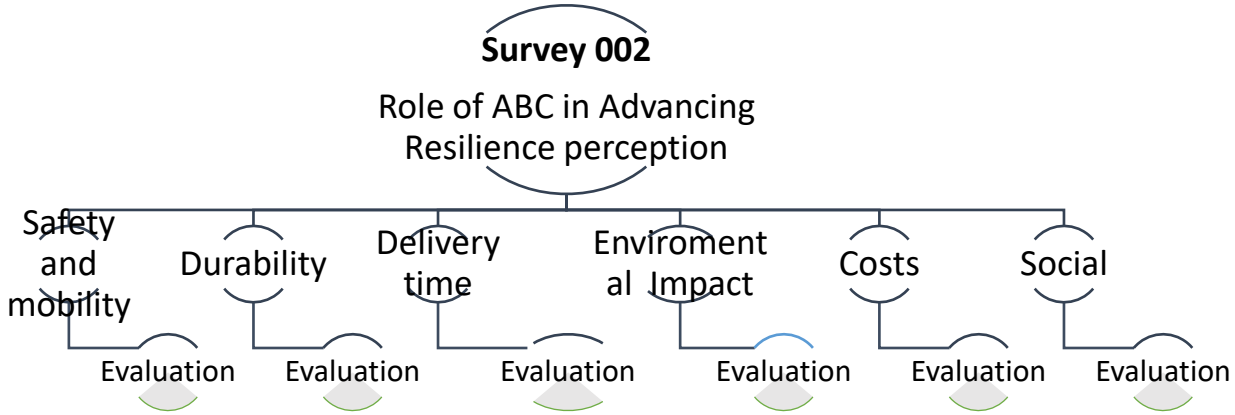
- Mention the current procedure for prioritizing Bridges for repair.
  Mentioned the preferred approach.
  Mention the major advantage.
  Mention the major disadvantage.

- Mention the current procedure for prioritizing Bridges for replacement.
  Mentioned the preferred approach.
  Mention the major advantage.
  Mention the major disadvantage.

- Do you leverage emerging technologies in data science in your decision-making regarding the pre-hazard preparedness and hazard recovery?
  Mention the technology that your department has used.

| **SURVEY Nº 002- Survey of stakeholders ABC** | |
|---|---|
| Objectives | • Gain insight of their **awareness, perception, and benefits** of ABC<br>• It is expected that the survey will help identify opportunities for ABC. |
| Tools | **Mental map Model** |
| Time | **10 minutes** |
| version | **D (Draft)** |
| Date | **08/30/2021** |

**Survey 2: Perception of ABC bridges**: This survey seeks to gain an insight of stakeholder perception and benefits of ABC to resilience. Accelerated construction techniques regarding safety and mobility, durability, delivery time, reduce environmental impact and costs are included in this survey.




**Survey**
**ABC perception**

Rank the benefit you perceive from ABC compared to conventional bridge engineering in each of the following:

*Safety and mobility: Time it takes to execute a new bridge or repair.*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |

*Durability: Performance of the structure in its lifetime.*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |

*Delivery time: Expected delivery time of the project*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |

*Environmental impact: Expected impact from the project to the environment.*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |

*Costs: Expected impact of costs.*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |

*Social: Expected social consequences to the Communities that are serviced by the infrastructure.*

Rank the benefit from 1-5.
Please provide a short explanation for your choice.

| | |
|---|---|
| 1 | NEGATIVE |
| 2 | |
| 3 | SIMILAR |
| 4 | |
| 5 | POSITIVE |