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 February 28, 2022

Submitted (Jointly) by:
Graduate Student- Paul Cancino[1]
Graduate Student- Mohamed Ibrahim [3]
PI: Dr. Islam M. Mantawy, Florida International University[2]
PI: Dr. Mohamed Moustafa, University of Nevada, Reno[3]
PI: Dr. Musharraf Zaman, University of Oklahoma[1]
Co-PI- Dr. Edward Cokely, University of Oklahoma[4]

[1]School of Civil Engineering and Environmental Science, University of Oklahoma,
[2]Department of Civil and Environmental Engineering, Florida International University
[3]Department of Civil and Environmental Engineering, University of Nevada, Reno
[4]Department of Psychology, University of Oklahoma, Norman

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
Florida International University
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 system 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: **70%**

In the fourth quarter, the literature review has been significantly updated with a focus on two main chapters that will also be addressed in the final report. The first chapter discusses the development history of the structural design philosophy, starting from the force-based design to performance-based design, and finally resilience-based design. Also, the most important components of the resilience-based design were studied. Most of the resilience metrics and definitions have been collected and summarized in tables. In the second chapter, the advances in the bridge design have been presented including the recently proposed AASHTO guidelines for seismic design of bridges.

During the fourth quarter, 54 additional sources have been added, resulting in a total of 164 resources. Additional three categories have been added, resulting in a total of 15 categories as shown in Figure 1 that shows the distribution of the information gathered and reviewed to date.

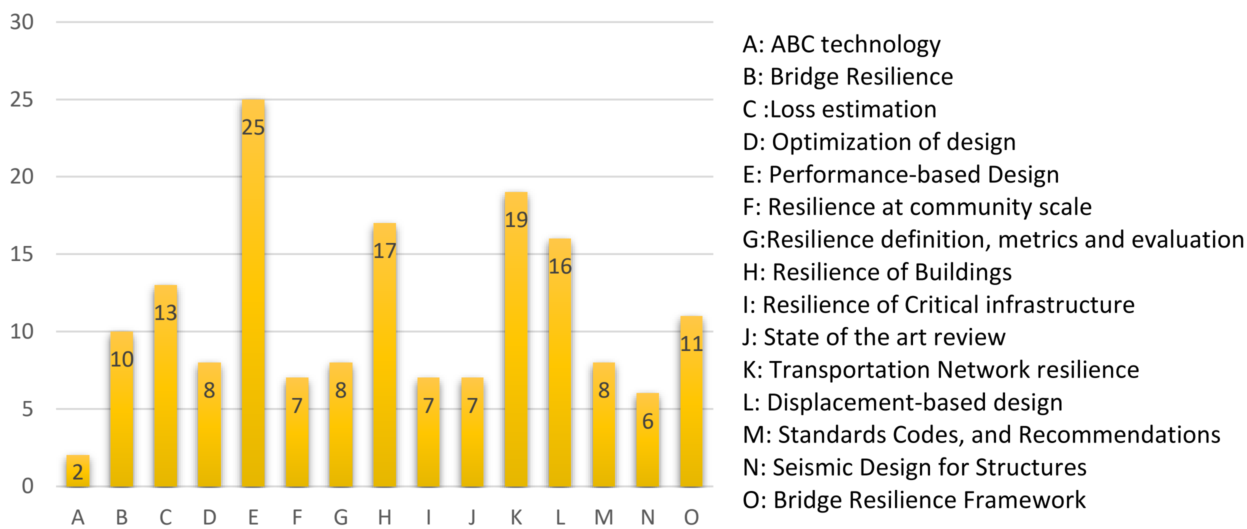

Figure 1: The distribution of the information gathered and reviewed to date

Until the end of the third quarter, more than 164 relevant studies have been reviewed. The most relevant conceptual thoughts have been presented from the existing literature and cited in the draft of the final report.

A combined list of all documents (journal, reports, and other materials) is included in Appendix 1. The new documents (No. 111 to No. 164) were added during the reporting period and highlighted in blue. This appendix also includes a full reference of each document including category, and subcategories.

The categories and subcategories considered (including the newly added) 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
Bridge Resilience framework
Earthquake and Hurricane
Earthquake and Tsunami Hazards
extreme hydrologic events
Flood and earthquake
flooding and scour
Flooding restauration models
Loss in functionality estimation
Manmade hazard: application to blast risk assessment
PEER Methodology
Seismic
Wave induce loads costal bridges
Displacement-based design
Comparison between the design methods
Concepts and procedures
Seismic design for bridges
Seismic design for buildings
Loss estimation
Cost of structural retrofitting
earthquake loss estimation methods
Estimation for the time loss
Estimation of the recovery time
Estimation of the time loss
Guidelines for construction cost estimation
Loss estimation: FEMA and Hazus-HM Applied to bridges
Loss estimation: FEMA P-58 applied to region

Model to estimate the time loss
the HAZUS technology
Total loss due to earthquake

Optimization of design

Functionality loss estimation
Multi-objective design models
Reliability analysis for budling resilience
Seismic optimization design model

Performance-based Design

Collapse prevention systems
Multi-hazard life cycle performance of building
Multi-hazard risk analysis
Multi-objective design models
Seismic assessment
Simplified building design approach
Structural health monitoring
Wind hazards for building

Resilience at community scale

Multi-hazard PEOPLES Resilience
Natural related issues due to hazards
Relationship between the community resilience to the performance of building
Seismic assessment
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
Natural related issues due to hazards
Resilience Metrics and case study
Seismic resilience in chapter 11

Resilience of Buildings

Definition, Metrics, and Valuation for Decision Making
Expected Seismic Performance of Code
Guidelines for Seismic Design of Buildings
implementation Guide
Methodology
Methodology for Assessing Environmental Impacts
Methodology supporting materials
Multi-hazard risk analysis
Organizational Resilience, Building Resilience, and Ambient Resilience
Recommendation for seismic evaluation
Reliability analysis for budling resilience

Reliability analysis for budling resilience
resilience-based earthquake design for new buildings
Tools for Seismic Design and Assessment

Resilience of Critical infrastructure

Comparison of Network resilience
Probabilistic Resilience Infrastructure
Reliability analysis for budling resilience
Resilience management ISO 31000 Risk Management
Resilience of lifelines: Seismic Hazard
Seismic demands identification
Societal Resilience
Theorical Classification of vulnerability

Seismic Design for Structures

Inelastic approach to identify the structural failure
Proportioning seismic resistant building
Responses of RC structure for building
Seismic response of nonlinear structures
Yield point spectra

Standards Codes, and Recommendations

Guidelines for multihazard designs
Guidelines for seismic rehabilitation
Provisions for Bridge design
Provisions for seismic rehabilitation
Recommended lateral force requirements

State of the art review

Cost and time estimation in construction
Disaster resilience individual and regional
Emergency Reconstruction of Critical infrastructure
Highway Bridges for Regional Risk and Resilience Assessment
Interdisciplinary Resilience International
Societal Resilience
Transportation asset resilience

Transportation Network resilience

Congestion Prediction Application of big Data
Consumer surplus economic impact studies
Cost-Based Post disaster 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 = 164

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 resiliency experts and state Dots'. In addition to providing useful information on risk and resilience framework, the survey seeks to identify topics and priorities for future research. The survey was fully developed through an online platform and will be sent out to the target professionals. It is expected to take about 15 minutes to complete the survey. This shorter period aimed at increasing participation (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) played 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.

<u>Description of work performed up to this period: **80%**</u>

The two surveys, as reported in the second quarter, were merged during the third quarter to avoid overwhelming the engineers with several surveys, this is expected to increase participation. Both Surveys were efficiently combining into one survey that cover the objectives of both surveys.

Survey (Includes contents of Survey 1 and 2): the two main areas that will be assessed are existing tools and current protocols, and perception of stakeholders, the specific objectives are listed below.

The survey focuses on the assessment of resilience tools, protocols, and perception of available tools. And also, 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 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.
- To gain an insight of social awareness, perception, and benefits of ABC; and
- To identify stakeholders.

The objective is to survey those who are familiar with resiliency within their agencies or those who make decisions on the recovery process after hazards and the preparedness process before hazards. Also, the survey was programmed using Qualtrics platform to have the survey ready for publishing online. In this period, the IRB (International review board) application was submitted for the resilience study. Since the survey is conducted on human subjects, the IRB application is required, including a training in ethics for the key personnel. During the next reporting period the survey will be launched, and the result recollected and processed.

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)

<u>Description of work performed up to this period: 45%</u>

For the development of the framework, several frameworks for different types of hazards were collected considering some of the following scenarios:

1- Single hazard
    a- Seismic hazard, or
    b- Flooding, or
    c- Fire, or
    d- Hurricanes, or
    e- Explosion/blast, or
    f- Environmental stressors
2- Multiple hazards based on seismic event as initial hazard followed by
    a- Tsunami, or
    b- Fire
3- Multiple hazards based on chronic environmental stressors (for example, corrosion) as the initial hazard followed by:
    a- Earthquake
    b- Earthquake then fire
    c- Earthquake then tsunami
    d- Fire

   e- Flooding (causing scour)
   f- Hurricanes
   g- Explosion/Blast
4- Multiple hazards based on flooding event as initial hazard followed by
   a- Earthquake
   b- Earthquake then fire
   c- Earthquake the tsunami
   d- Fire
   e- Environmental stressor (accelerated corrosion)
   f- Hurricanes
   g- Explosion/Blast

Figure 2 shows some initial possible combination between hazards. The frameworks collected are listed under the category of Bridge resilience framework from the literature review table listed in Appendix 1.

Additionally, it was identified that the current state of bridges should be obtained for determining the bridge parameters. The long-term bridge program (LTBP) of the FHWA updates bridge information periodically; this database can be accessed and cover bridges over the country. The LTBP Program is a long-term research effort authorized by the US Congress to collect and update high-quality bridge data from highway bridges nationwide. The information collected by the LTBP Program and the National Bridge Inventory (NBI) is disseminated and displayed through InfoBridge web portal.

The framework (depicted in Figure 3) can be organized in several steps to fit the different hazards types. For example, the framework starts with selecting a specific bridge. The following steps will be carried out after the selection of a bridge structure:

1- Define bridge parameters from different datasets such as LTBP or any other database such as bridge location, bridge system, materials for super and substructures, geological information, load rating, bridge condition, inspection reports, among others;
2- After defining the bridge location from Step 1, the applicable hazard should be defined, such as flooding, earthquakes, hurricanes, tsunami, fire, chronic environmental events, explosion, etc, based on bridge location.
3- After selecting bridge parameters, the possible hazards that may affect the bridge structure are chosen according to the expected risk for the bridge location. Hazard that may affect one bridge doesn't necessarily affect others. Therefore, after the selection of applicable hazards, a risk assessment and sorting must be realized to determine the hazards that are relevant to the structure.
4- For the hazard with the highest rank (Hazard #1) from risk assessment and sorting
   a- user has to utilize the specific flowchart to obtain structural resilience metrics (Resiliency loss indicator, Robustness, Rapidity, etc.); an example of a specific flowchart for seismic hazard is being developed under task 4.
   b- After obtaining structural resilience metrics, user will translate structural resilience metrics into global resilience matrices such as (number of lanes or vertical capacity or lateral capacity)

c- After (4-a) the global resilience metrics are checked against allowable global resilience metrics (either accepted (safe) or not accepted (require strengthening until accepted)

5- Repeat Step 4 for sequential hazards with lower ranks

6- Repeat Step 4 for multi-hazard scenario (examples are depicted in Figure 2).

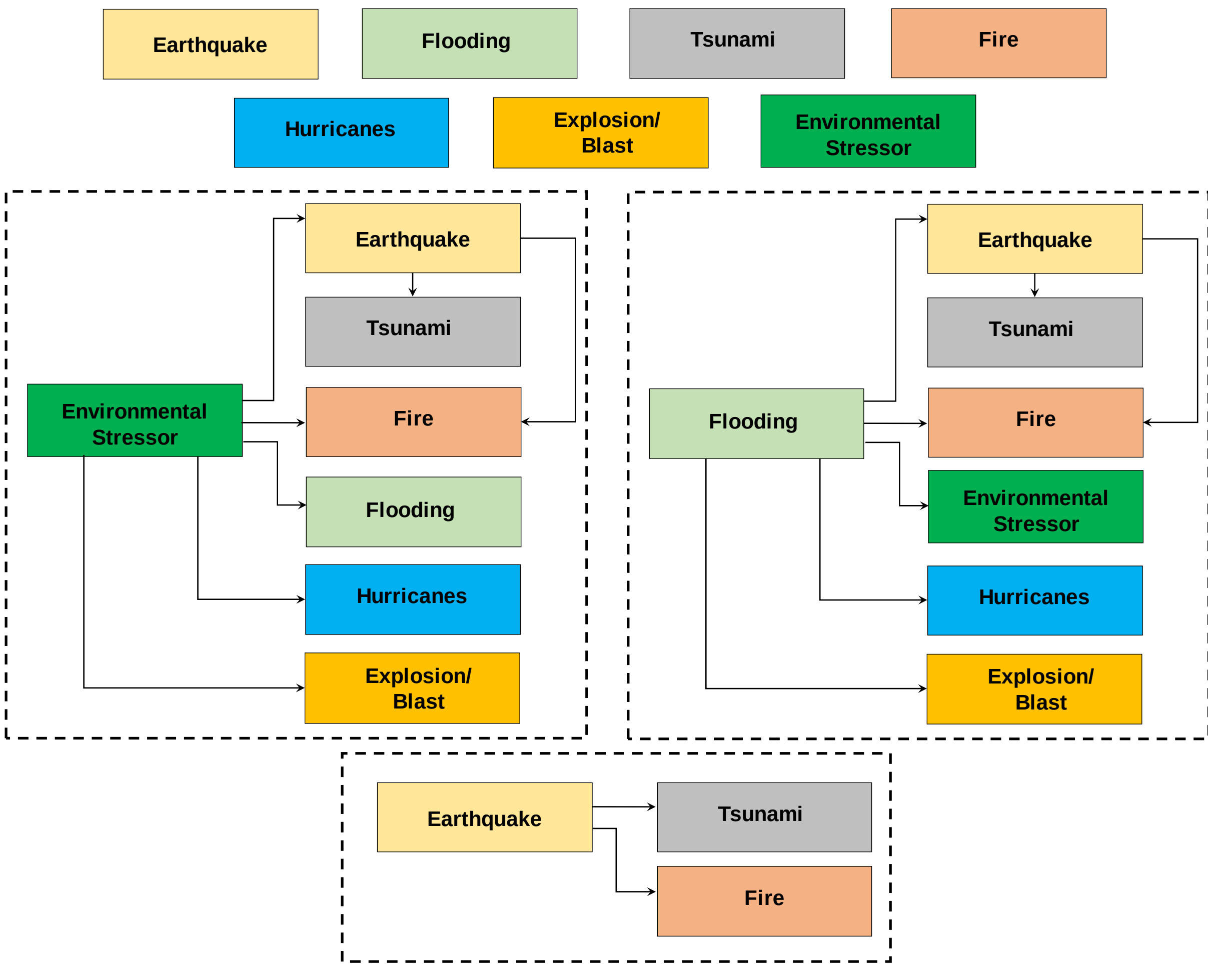

Figure 2: Possible hazard combinations

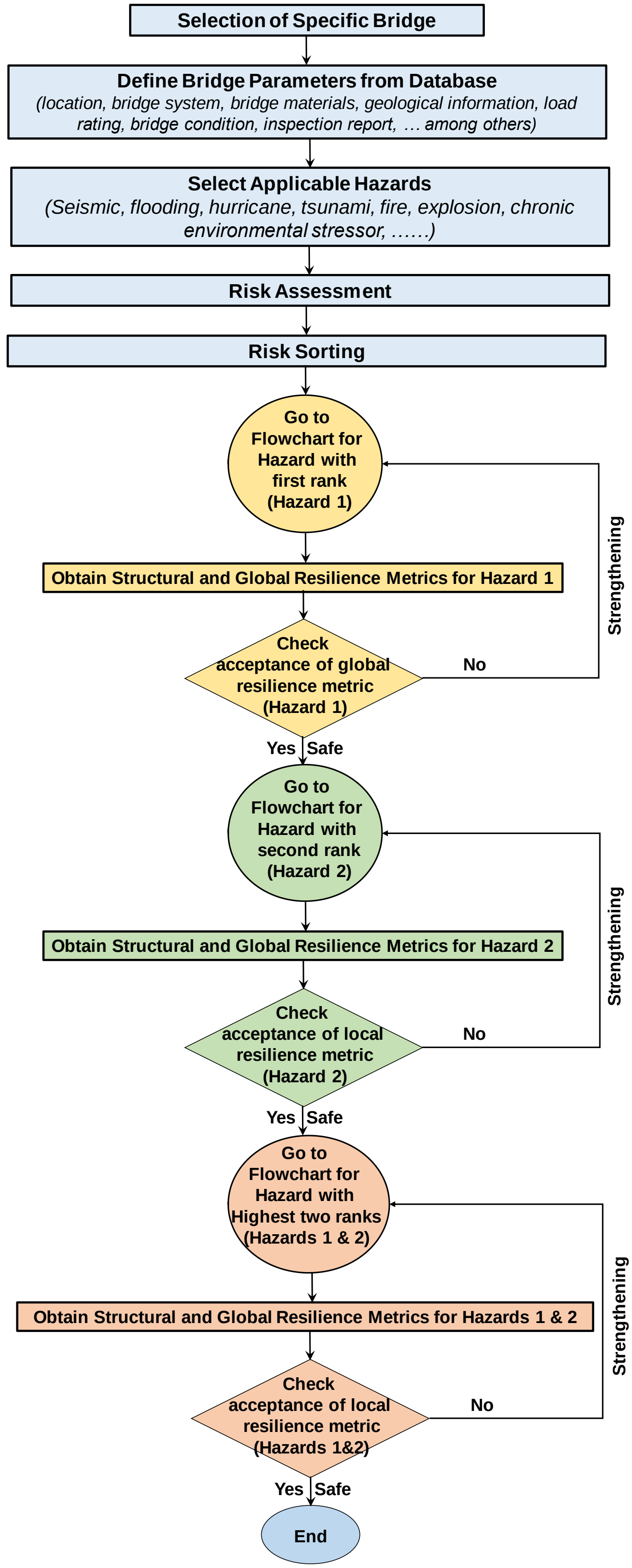

Figure 3: Preliminary framework for assessing the risk and resiliency of bridges.

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: 30%

It was identified that some advanced tools have been developed for seismic hazards to help in the resilience assessment of bridges. Using these available tools, a more specific resilience framework will be developed for seismic hazards. The US Geological Survey (USGS) has developed ShakeCast and ShakeMap that have been identified as valuable tools for the assessment of bridges in the US. ShakeMap uses earthquake location and magnitude to project a map view of expect ground-shaking amplitudes using a ground motion attenuation relation (GMPE) for prediction, and ShakeCast lists potentially affected bridges reported in order of inspection priority (Figure 4). The image below shows the expected damage in a color scale. After the calculation of damage, the resilience assessment should follow, so that the recovery of the functionality in time is considered along with the resilience metrics suggested in the 4-R methodology.

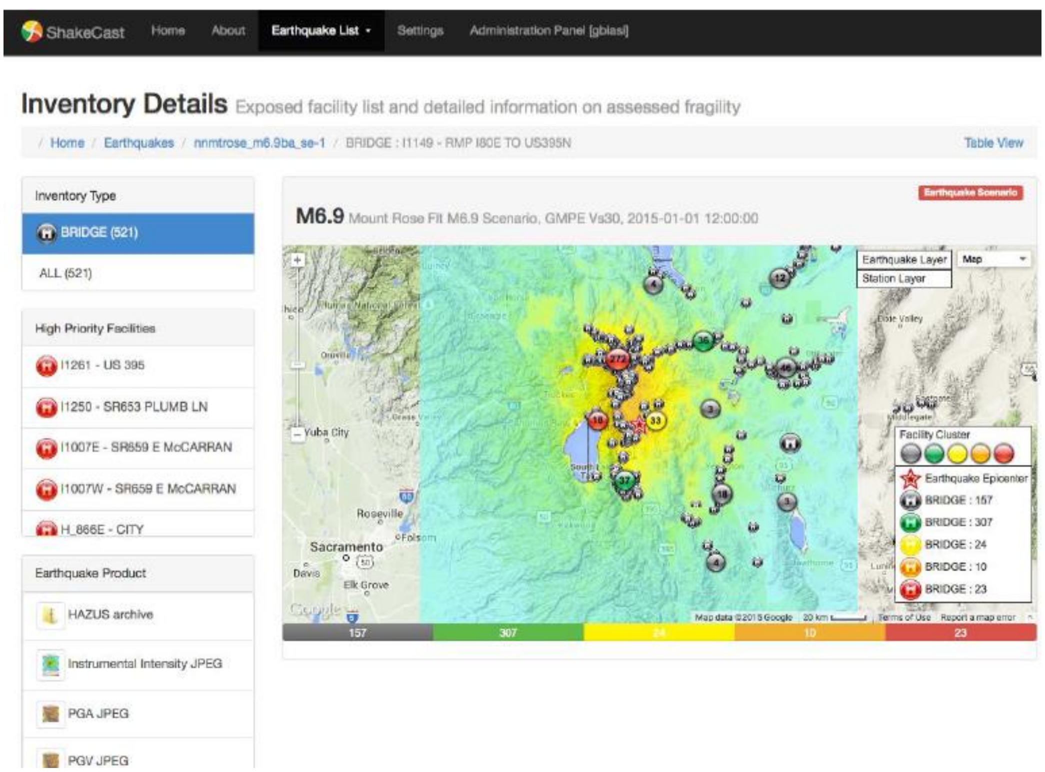

Figure 4: ShakeCast view showing bridges and damage states from earthquake scenario.

Task 5- Final Report.

In this task, a 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 and perception 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 a 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	**50%**

Research Tasks	2021									2022								
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
Task 1 – Conducting a literature review on risk and resilience of roadway bridges under natural and man-made hazards.					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.						80%												
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										45%								
Task 4- Development of a specific resilience framework.										30%								
Task 5- Final Report.																		

Work performed

Work to be performed

7. References

Appendix 1: List of literature review by category

Appendix 2: Survey (Includes contents of Survey 1 and 2)

Appendix 1: List of literature review by category

Categories	Count of Category
ABC technology	2
Bridge Resilience	10
Loss estimation	13
Optimization of design	8
Performance-based Design	25
Resilience at community scale	7
Resilience definition, metrics and evaluation	8
Resilience of Buildings	17
Resilience of Critical infrastructure	7
State of the art review	7
Transportation Network resilience	19
Displacement-based design	16
Standards Codes, and Recommendations	8
Seismic Design for Structures	6
Bridge Resilience framework	11
Grand Total	**164**

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

#	Full Reference	Category	Sub-category
1	Seismic Resilience of Transportation Networks with Deteriorating Components	Bridge Resilience framework	Loss in functionality estimation
2	The REDI™ rating system: a framework to implement resilience-based earthquake design for new buildings	Resilience of Buildings	Definition, Metrics, and Valuation for Decision Making
3	Systems Resilience for Multihazard Environments: Definition, Metrics, and Valuation for Decision Making	Resilience definition, metrics and evaluation	Natural related issues due to hazards
4	A stochastic computational framework for the joint transportation network fragility analysis and traffic flow distribution under extreme events	Transportation Network resilience	Seismic Resilience + aging transportation network
5	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
6	Multiple-Hazard Fragility and Restoration Models of Highway Bridges for Regional Risk and Resilience Assessment in the United States	State of the art review	Societal Resilience
7	Emergency Reconstruction of Critical Transportation Infrastructure	State of the art review	Highway Bridges for Regional Risk and Resilience Assessment
8	Lifelines in earthquakes a case study based on wellington	Resilience of Critical infrastructure	Reliability analysis for budling resilience
9	Post-hazard flow capacity of bridge transportation network considering structural deterioration of bridges	Transportation Network resilience	fragility analysis and traffic flow distribution under extreme events
10	Post-earthquake functionality of highway overpass bridges	Bridge Resilience	Functionality of bridge
11	Rapid seismic damage evaluation of bridge portfolios using machine learning techniques	Transportation Network resilience	Flow capacity of bridges Network Resilience
12	Multi-Scale Classification of Ontario Highway Infrastructure: A Network Theoretic Approach to Guide Bridge Rehabilitation Strategy	Resilience of Critical infrastructure	Resilience of lifelines: Seismic Hazard
13	Resilience of Regional Transportation Networks Subjected to Hazard-Induced Bridge Damages	Transportation Network resilience	Seismic Evaluation of bridge portfolio using machine learning
14	Predicting Congestion States from Basic Safety Messages by Using Big-Data Graph Analytics	Transportation Network resilience	Hazard-Induced Bridge Damages

#	Full Reference	Category	Sub-category
15	Functionality-fragility surfaces	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions
16	Resilience-based design of urban centers: application to blast risk assessment	Resilience of Critical infrastructure	Theorical Classification of vulnerability
17	Resilience Metrics	Resilience definition, metrics and evaluation	Definition, Metrics, and Valuation for Decision Making
18	Measurement Frameworks and Metrics for Resilient Networks and Services: Technical report	Resilience definition, metrics and evaluation	Resilience Metrics and case study
19	Probabilistic Resilience-Guided infrastructure risk Management	Bridge Resilience framework	Manmade hazard: application to blast risk assessment
20	Redi™ Rating System: Resilience-based Earthquake Design Initiative for the Next Generation of Buildings	Resilience of Buildings	resilience-based earthquake design for new buildings
21	Volume 1 – Methodology Second Edition. Seismic Performance Assessment of Buildings	Resilience of Buildings	Organizational Resilience, Building Resilience, and Ambient Resilience
22	Volume 2 – Implementation Guide. Seismic Performance Assessment of Buildings	Resilience of Buildings	Methodology
23	Volume1 Methodology supporting materials. Seismic Performance Assessment of Buildings	Resilience of Buildings	implementation Guide
24	Volume 4 – Methodology for Assessing Environmental Impacts. Seismic Performance Assessment of Buildings	Resilience of Buildings	Methodology supporting materials
25	Volume 5 – Expected Seismic Performance of Code-Conforming Buildings. Seismic Performance Assessment of Buildings	Resilience of Buildings	Methodology for Assessing Environmental Impacts
26	Guidelines for Performance-Based Seismic Design of Buildings	Resilience of Buildings	Expected Seismic Performance of Code
27	A Guide to State-of-the-Art Tools for Seismic Design and Assessment. Building the Performance, You Need	Resilience of Buildings	Guidelines for Seismic Design of Buildings
28	Proposed AASHTO Guidelines for Performance-Based Seismic Bridge Design	Bridge Resilience	Guidelines for Seismic Performance Assessment of Bridges
29	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

#	Full Reference	Category	Sub-category
30	Innovative Bridge Designs for Rapid Renewal ABC Toolkit	ABC technology	ABC Toolkit for design recommendations
31	Management of Resilience in Civil Infrastructure Systems: An Interdisciplinary Approach	State of the art review	Emergency Reconstruction of Critical infrastructure
32	Seismic Fragility Methodology for Highway Bridges	Bridge Resilience	Seismic fragility curves for Bridges
33	Retrofitted Bridge Fragility Analysis for Typical Classes of Multispan Bridges	Bridge Resilience	Fragility analysis for Retrofit Bridges
34	A Scalable Framework for Assessing Seismic Resilience of Communities	Resilience at community scale	Seismic assessment
35	Resilience Criteria for Seismic Evaluation of Existing Buildings: A Proposal to Supplement ASCE 31 for Intermediate Performance Objectives	Resilience of Buildings	Tools for Seismic Design and Assessment
36	Application of the FEMA-P58 methodology for regional earthquake loss prediction	Loss estimation	Loss estimation: FEMA P-58 applied to region
37	A framework for defining and measuring resilience at the community scale: the people's resilience framework	Resilience at community scale	Seismic Resilience of Communities
38	A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities	Resilience at community scale	Multi-hazard PEOPLES Resilience
39	Comparative Visualization of Predicted Disaster Resilience	Resilience definition, metrics and evaluation	Measurement Frameworks and Metrics
40	Conceptualizing and Measuring Resilience	Resilience definition, metrics and evaluation	Method for evaluation Comparing resilience
41	From Risk Management to Resilience Management in Critical Infrastructure	Resilience of Critical infrastructure	Probabilistic Resilience Infrastructure
42	Fragility of transport assets exposed to multiple hazards: State-of-the-art review toward infrastructural resilience	State of the art review	Interdisciplinary Resilience International
43	ISRA: IMPROVER societal resilience analysis for critical infrastructure	Resilience of Critical infrastructure	Resilience management ISO 31000 Risk Management
44	Disaster Resilience: A Guide to the Literature	State of the art review	Transportation asset resilience
45	Effective sampling of spatially correlated intensity maps using hazard quantization Application to seismic events	Transportation Network resilience	Congestion Prediction Application of big Data
46	Metrics and algorithm for optimal retrofit of resilient transportation network	Transportation Network resilience	Intensity maps for seismic hazard
47	Empirically quantifying city-scale transportation system resilience to extreme event	Transportation Network resilience	optimal retrofit

#	Full Reference	Category	Sub-category
48	Transportation sector resilience	Transportation Network resilience	empirical GPS data
49	Resilience in Transportation Systems	Transportation Network resilience	potential gaps and opportunities
50	Integrating Risk and Resilience Approaches to Catastrophe management in engineering systems	Transportation Network resilience	framework for resilience in transportation system
51	Measuring the resilience of transport	Transportation Network resilience	Integrating risk and resilience to Catastrophe management
52	Resilience and Sustainability of Civil Infrastructure Toward a Unified Approach.	Transportation Network resilience	Resilience assessment framework
53	Optimal Resilience- and Cost-Based Postdisaster Intervention Prioritization for Bridges along a Highway Segment	Transportation Network resilience	Resilience and Sustainability
54	The framework for calculating the measure of resilience for intermodal transportation systems	Transportation Network resilience	Cost-Based Post disaster Intervention
55	Incorporating transportation network modeling tools within transportation economic impact studies of disasters	Transportation Network resilience	framework for resilience in transportation system
56	FRAMEWORK OF CALCULATING THE MEASURES OF RESILIENCE (MOR) FOR INTERMODAL TRANSPORTATION SYSTEMS	Transportation Network resilience	Consumer surplus economic impact studies
57	A Comparison of Transportation network resilience under simulated system optimum and user equilibrium conditions	Transportation Network resilience	framework for measures of resilience
58	Perspectives On European Earthquake and sismology	Resilience definition, metrics and evaluation	Concepts and measurement of resilience
59	HAZUS Earthquake Loss Estimation Methods	Loss estimation	earthquake loss estimation methods
60	Resilience Primer for Transportation Executives	Resilience of Critical infrastructure	Societal Resilience
61	On the use of filters to facilitate the post-optimal analysis of the Pareto solutions in multi ojective optimization	Optimization of design	Functionality loss estimation
62	A seismic optimization procedure for reinforced concrete framed buildings based on eigenfrequency optimization	Optimization of design	Multi-objective design models

#	Full Reference	Category	Sub-category
63	Evaluation of the Methodology to Select and Prioritize	Optimization of design	Seismic optimization design model
64	Collapse Indicators in Older Concrete Buildings	Performance-based Design	Multi-objective design models
65	First-order reliability approach to quantify and improve building portfolio resilience	Resilience of Buildings	Recommendation for seismic evaluation
66	Exploring the concept of seismic resilience for acute care facilities	Resilience of Critical infrastructure	Comparison of Network resilience
67	NEHRP recommended seismic provisions for new buildings and other structures	Resilience of Buildings	Reliability analysis for budling resilience
68	Framework for incorporating probabilistic building performance in the assessment of community seismic resilience	Resilience at community scale	Seismic Resilience of Communities
69	Introduction to resilience-based design (RBD)	Resilience definition, metrics and evaluation	Seismic resilience in chapter 11
70	Dynamic response of tall buildings to wind loads by reduced order equivalent shear-beam models	Performance-based Design	Structural health monitoring
71	Estimating downtime in loss modeling	Loss estimation	the HAZUS technology
72	Progress and challenges in seismic performance assessment	Performance-based Design	Wind hazards for building
73	Functional Recovery: A Conceptual Framework with Policy Options.	Loss estimation	Model to estimate the time loss
74	Rigid body response & performance based design of seismically isolated structures	Performance-based Design	Seismic assessment
75	Significant factors causing delay in the UAE construction industry	Loss estimation	Estimation of the recovery time
76	FEMA P-58-3: Seismic performance assessment of buildings.	Performance-based Design	Seismic assessment
77	Performance-based optimum seismic design of steel structures by a modified firefly algorithm and a new neural network	Performance-based Design	Seismic assessment
78	Engineering, procurement and construction cost and schedule performance leading indicators: state-of-the-art review	State of the art review	Disaster resilience individual and regional
79	Seismic loss and downtime assessment of existing tall steel-framed buildings and strategies for increased resilience	Loss estimation	Estimation of the time loss

#	Full Reference	Category	Sub-category
80	Risk Analysis for Structures Exposed to Several Multi-Hazard Sources	Resilience of Buildings	Recommendation for seismic evaluation
81	Multi-hazard performance of steel moment frame buildings with collapse prevention systems in the central and eastern United States	Performance-based Design	Seismic assessment
82	Simplified design of reinforced concrete buildings	Performance-based Design	Collapse prevention systems
83	Performance-based seismic design of steel frames utilizing charged system search optimization.	Performance-based Design	Simplified building design approach
84	Performance-based earthquake engineering	Performance-based Design	Seismic assessment
85	Defining resilience for the US building industry	Resilience definition, metrics and evaluation	Definition, Metrics, and Valuation for Decision Making
86	Framework for multihazard risk assessment and mitigation for wood-frame residential construction	Resilience of Buildings	Multi-hazard risk analysis
87	A risk de-aggregation framework that relates community resilience goals to building performance objectives	Resilience at community scale	Seismic Resilience of Communities
88	Multiobjective optimization for performance-based seismic design of steel moment frame structures	Optimization of design	Multi-objective design models
89	Community-resilience-based design of the built environment	Resilience at community scale	Relationship between the community resilience to the performance of building
90	Review of the state of the art in assessing earthquake-induced loss of functionality in buildings	State of the art review	Cost and time estimation in construction
91	A framework for linking community-resilience goals to specific performance targets for the built environment	Resilience at community scale	Natural related issues due to hazards
92	Virtual Inspector and its application to immediate pre-event and post-event earthquake loss and safety assessment of buildings	Loss estimation	Estimation for the time loss
93	A framework methodology for performance-based earthquake engineering	Performance-based Design	Seismic assessment
94	2020 National Construction Estimator	Loss estimation	Total loss due to earthquake

#	Full Reference	Category	Sub-category
95	Building construction cost data	Loss estimation	Guidelines for construction cost estimation
96	Resilient San Francisco:Stronger Today, Stronger Tomorrow	Resilience of Critical infrastructure	Seismic demands identification
97	Seismic structural design methodology for inelastic shear buildings that regulates floor accelerations	Performance-based Design	Seismic assessment
98	Practical solutions for multi-objective optimization: an application to system reliability design problems	Optimization of design	Multi-objective design models
99	Optimum performance-based seismic design of frames using metaheuristic optimization algorithms	Optimization of design	Multi-objective design models
100	Multihazard Interaction Effects on the Performance of Low-Rise Wood-Frame Housing in Hurricane-Prone Regions	Performance-based Design	Seismic assessment
101	Efficient strategies for reliability-based optimization involving non-linear, dynamical structures	Optimization of design	Multi-objective design models
102	Simplified models for assessment and optimal redesign of irregular planar frames	Performance-based Design	Multi-hazard risk analysis
103	Multi-hazard life-cycle performance of tall buildings under seismic and wind loads	Performance-based Design	Simplified building design approach
104	Life-cycle cost optimization of the seismic retrofit of existing RC structures	Loss estimation	Guidelines for construction cost estimation
105	Performance-based seismic design of controlled rocking steel braced frames	Performance-based Design	Multi-hazard life cycle performance of building
106	Pruning and ranking the Pareto optimal set, application for the dynamic multi-objective network design problem	Optimization of design	Reliability analysis for budling resilience
107	Reliability-based optimum seismic design of structures using simplified performance estimation methods	Resilience of Buildings	Multi-hazard risk analysis
108	Probabilistic Prediction of Postdisaster Functionality Loss of Community Building Portfolios Considering Utility Disruptions	Loss estimation	Cost of structural retrofitting
109	Performance-Based Economical Seismic Design of Multistory Reinforced Concrete Frame Buildings and Reliability Assessment	Resilience of Buildings	Reliability analysis for budling resilience

#	Full Reference	Category	Sub-category
110	Integrated reliability-based seismic drift design optimization of base-isolated concrete buildings	Resilience of Buildings	Reliability analysis+D97:D111 for budling resilience
111	Force-based vs. direct displacement-based design of buildings with seismic isolation	Displacement-based design	Comparison between the design methods
112	Highlighting differences between force-based and displacement-based design solutions for reinforced concrete frame structures	Displacement-based design	Comparison between the design methods
113	The limitations and performances of different displacement based design methods	Displacement-based design	Comparison between the design methods
114	Displacement-Based Design of RC Structures Subjected to Earthquakes	Displacement-based design	Seismic design for buildings
115	NEHRP Guidelines and Commentary for the Seismic Rehabilitation of Buildings	Standards Codes, and Recommendations	Guidelines for seismic rehabilitation
116	Deformation-controlled earthquake-resistant design of rc buildings	Displacement-based design	Seismic design for buildings
117	A simplified procedure to assess the seismic response of nonlinear structure	Seismic Design for Structures	Seismic response of nonlinear structures
118	A Nonlinear Analysis Method for Performance-Based Seismic Design	Performance-based Design	Seismic assessment
119	The Capacity Spectrum Method as a Tool for Seismic Design	Displacement-based design	Seismic design for buildings
120	ATC-40- Seismic evaluation and retrofit of concrete buildings	Standards Codes, and Recommendations	Provisions for seismic rehabilitation
121	Approximate inelastic procedures to identify failure mechanisms from higher mode effects	Seismic Design for Structures	Inelastic approach to identify the structural failure
122	Capacity-demand-diagram methods based on inelastic design spectrum	Seismic Design for Structures	Inelastic approach to identify the structural failure
123	Proportioning of Earthquake-Resistant RC Building Structures	Seismic Design for Structures	Proportioning seismic resistant building
124	Responses of reinforced concrete structures to earthquake motions	Seismic Design for Structures	Responses of RC structure for building
125	1988 SEAOC and UBC seismic provisions	Standards Codes, and Recommendations	Provisions for seismic rehabilitation
126	Yield point spectra for seismic design and rehabilitation	Seismic Design for Structures	Yield point spectra
127	Direct displacement-based design: Use of inelastic vs. Elastic design spectra	Displacement-based design	Comparison between the design methods
128	Displacement-based design of RC bridge columns in seismic regions	Displacement-based design	Seismic design for bridges
129	SEAOC, Recommended lateral force requirements and commentary	Standards Codes, and Recommendations	Recommended lateral force requirements
130	Concepts and procedures for direct displacement-based design and assessment	Displacement-based design	Concepts and procedures

#	Full Reference	Category	Sub-category
131	Seismic design of R/C buildings with the aid of advanced analytical techniques	Displacement-based design	Seismic design for buildings
132	Performance-based design in earthquake engineering: State of development	Performance-based Design	Seismic assessment
133	Performance based seismic design	Performance-based Design	Seismic assessment
134	Performance-based seismic bridge design for damage and loss limit states	Performance-based Design	Seismic assessment
135	Performance-based seismic design of unbonded precast post-tensioned concrete filled GFRP tube piers	Performance-based Design	Seismic assessment
136	Canadian Highway Bridge Design Code	Standards Codes, and Recommendations	Provisions for Bridge design
137	LRFD Seismic analysis and design of bridges reference manual	Standards Codes, and Recommendations	Provisions for Bridge design
138	The gerald desmond cable-stayed bridge-a case study in performance-based seismic design	Performance-based Design	Seismic assessment
139	Performance-based seismic design for the vancouver evergreen line rapid transit project-process, challenges, and innovative design solutions	Performance-based Design	Seismic assessment
140	Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds	Standards Codes, and Recommendations	Guidelines for multihazard designs
141	Seismic Retrofitting Manual for Highway Structures: Part 1	Standards Codes, and Recommendations	Guidelines for seismic rehabilitation
142	Performance-based seismic design of nonstructural building components: The next frontier of earthquake engineering,"	Performance-based Design	Seismic assessment
143	Performance-Based Seismic Bridge Design	Performance-based Design	Seismic assessment
144	Seismic fragility of typical bridges in moderate seismic zones	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions
145	Seismic Fragility Analysis of Highway Bridge.	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions
146	Fragility analysis of bridges under ground motion with spatial variation	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions
147	Fragility assessment of highway bridges: a state-of-the-art review	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions
148	Nonlinear Static Procedure for Fragility Curve Development	Bridge Resilience	Functionality-Fragility Surface: Fragility Curves and Restoration Functions

#	Full Reference	Category	Sub-category
149	Probabilistic Methodologies for Prediction of Post-Earthquake Bridge Repair Costs and Repair Times	Loss estimation	Total loss due to earthquake
150	Energy-based Seismic Design of Structures using Yield Mechanism and Target Drift	Displacement-based design	Concepts and procedures
151	Implementation of inelastic displacement patterns in direct displacement-based design of continuous bridge structures	Displacement-based design	Concepts and procedures
152	Evaluation of Iterative DBD procedures for bridges	Displacement-based design	Comparison between the design methods
153	Seismic performance comparison between direct displacement-based and force-based design of a multi-span continuous reinforced concrete bridge with irregular column heights	Displacement-based design	Comparison between the design methods
154	Application of direct displacement based design to long span bridges	Displacement-based design	Seismic design for bridges
155	A displacement-based approach for the seismic design of continuous concrete bridges	Displacement-based design	Seismic design for bridges
156	Post-Earthquake Assessment of Nevada Bridges Using ShakeMap/ShakeCast	Bridge Resilience framework	Seismeic
157	Vulnerability of bridges to individual and multiple hazards-floods and earthquakes	Bridge Resilience framework	Flood and earthquake
158	Multi-hazard risk assessment of highway bridges subjected to earthquake and hurricane hazards	Bridge Resilience framework	Earthquake and Hurricane
159	Review of resilience assessment of coastal bridges to extreme wave-induced loads	Bridge Resilience framework	Wave induce loads costal bridges
160	Resilience of critical structures, infrastructures and communities	Bridge Resilience framework	PEER Methodology
161	Multihazard Damage and Loss Assessment of Bridges in a Highway Network Subjected to Earthquake and Tsunami Hazards	Bridge Resilience framework	Earthquake and Tsunami Hazards
162	Resiliency planning: prioritizing the vulnerability of coastal bridges to flooding and scour	Bridge Resilience framework	flooding and scour
163	Restoration models for quantifying flood resilience of bridges	Bridge Resilience framework	Flooding restauration models
164	Risk-based cost-benefit analysis for the retrofit of bridges exposed to extreme hydrologic events considering multiple failure modes	Bridge Resilience framework	extreme hydrologic events

Appendix 2: Survey (Includes contents of Survey 1 and 2)

SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION ON THE CURRENT PRACTICE OF ASSESSMENT OF RISK AND RESILIENCE OF BRIDGES TO NATURAL HAZARDS AND MAN-MADE HAZARDS

Background and Goal

This survey is conducted as part of a collaborative research project funded by the Accelerated Bridge Construction Center (ABC-UTC) at Florida International University. University of Oklahoma and University of Nevada-Reno are also involved in this project. We greatly appreciate your time and assistance in completing this survey.

Closure of a single bridge within a transportation network due to natural hazards such as earthquake, flood, hurricane, and fire can lead to substantial disruption to the entire network. Assessment of risk and resilience of existing bridges and new bridges, including ABC (accelerated bridge construction) bridges, accelerated upgrade and accelerated repair are important to devise pre-hazard preparedness plans, post-hazard mitigation response strategies and improve the recovery time. In this survey we seek to document and synthesize the current state of practice related to assessment of risk and resilience of bridges. We believe input from people who are familiar with resilience of bridges in their agencies or who make decisions regarding the recovery process after hazards and the preparedness process before hazards, will be a great resource in this regard.

We greatly appreciate your help in documenting the current practice of your DOT regarding the assessment of risk and resilience of bridges. Also, this survey is expected to help identify future opportunities for research and develop tools for addressing resilience of bridges.

Who Should Fill Out This Survey?

Different state DOTs in the country have differences in the organizational structure. So, this survey is being sent to the division/department that deals with bridges. We request that this survey be directed to the appropriate person(s) within the organization. Our intent is to survey those who are familiar with resiliency within their agencies or those who make decisions on the recovery process after hazards and the preparedness process before hazards.

It would be helpful to have several responses from the same DOT, if possible, to capture different roles and views of those completing the survey. We greatly appreciate your time and assistance.

When is This Survey Due?

Please respond to this survey by **April 30, 2022.**

Online Consent to Participate in Survey

Please read this section carefully **BEFORE** agreeing to take part in this survey.

What is the purpose of this research?

The purpose of this research is to document and synthesize the current state of practice related to assessment of risk and resilience of bridges. We believe input from people who are familiar with resilience of bridges in their agencies or who make decisions regarding the recovery process after hazards and the preparedness process before hazards, will be a great resource in this regard.

What will I be asked to do?

You will be asked to answer questions about your perceptions of risk and resilience of bridges, resilience tools and software, hazard prediction and Accelerated Bridge Construction (ABC).

How long will this take?

Your participation is expected to take 15-30 minutes.

Is there any age restriction to take this survey?

You must be 18 years or above to participate in this survey..

What are the risks and/or benefits if I participate?

There are no risks or benefits from participating in this study. We greatly appreciate your help in documenting the current practice of your DOT regarding the assessment of risk and resilience of bridges. This survey is expected to help identify future opportunities for research and develop tools for addressing resilience of bridges.

Will I be compensated for participating?

You will not be compensated for your time and participation in this research.

Who will see my information?

We never release or sell any personally identifiable information. All data used for analysis are stored in an anonymous coded format. Your personal data will never be identifiable in any publication produced by the researchers at the University of Oklahoma or by our collaborators. Please note: Data that are collected online or in connection with partner organizations rely on existing privacy and security technologies. Although data files are always ultimately stored in coded and anonymous formats, we cannot guarantee that personal information shared over the internet will not be subject to data breaches from hacking, viruses, or similar during transmission. No assurance can be made regarding the data you provide to any third-party partner organization for purposes other than this research.

What will happen to my data in the future?

After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you.

Do I have to participate?

No. If you do not participate, you will not be penalized or lose benefits or services related to the research. If you decide to participate, you don't have to answer all questions and can stop participating at any time.

Who do I contact with questions, concerns or complaints?

For any technical questions or additional information, please contact the following people:

- Islam Mantawy (imantawy@fiu.edu)
- Mohamed Moustafa (mmoustafa@unr.edu)

For other questions related to this survey, please contact:

- Madhuri Ramasubramanian (Madhuri.Ramasubramanian-1@ou.edu)
- Edward T. Cokely (cokely@ou.edu)

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research, and wish to talk to someone other than the researcher.

Please print this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research.

☐ I agree to participate
☐ I do not agree to participate

Age:

You must be at least 18 years of age to participate in this survey. Are you at least 18 years old?

☐ Yes
☐ No

Your Agency/Organization

Your Position

Survey Questionnaire

Question 1 (ABC Perception): Using the options below, please provide your perception on safety and mobility, durability, delivery time, environmental impact, costs, and social impacts of the Accelerated Bridge Construction (ABC) techniques compared to conventional projects.

Perceived benefit	Significantly positive	Positive	No impact	Negative	Significantly negative
Safety and mobility: Safety of travelling public and workers, mobility is impact of construction on traffic flow					
Durability: Performance of the structure in its lifetime					
Delivery time: Expected delivery time of the project					
Environmental impact: Expected impact from the project on the environment					
Cost:					
Social: Expected social consequences to the Communities that are serviced by infrastructure					

Please provide a short explanation for your choice above. (optional)

Safety and Mobility

Durability

Delivery Time

Environmental Impact

Cost

Social

Question 2 (Quality): Please select the most suitable definition of a resilient structure from the following definitions, given your understanding of resilience.

- ☐ **Resilience** means the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents. *Presidential Policy Directive (PPD-21)*

- ☐ **Resilience** is ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events, *National Research Council*

- ☐ **Resilience** refers to the capability to mitigate against significant all-hazards risks and incidents, and to expeditiously recover and reconstitute critical services with minimum damage to public safety and health, the economy, and national security, ASCE Committee on Critical Infrastructure

- ☐ **Resilience** as the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient system depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event. *National Infrastructure Advisory Council*

- ☐ **Resilience** is the ability of a system or organization to withstand and recover from adversity, *Civil Contingencies Secretariat of the Cabinet Office, London, United Kingdom*

- ☐ I am familiar with another definition of **Resilience** (please use the box below to write the definition)

Question 3 (Type of Natural Hazards): What natural hazards are of concern to your agency in assessing the risk and resilience of bridges? For each hazard, please indicate the degree of importance on a scale of 1 (none) to 5 (very important).

Note: If needed, please use the last three boxes to specify other hazards and rate according to their relative importance.

Hazards	Rate from [1 – 5]
Coastal Surge	
Earthquake	
Explosion	
Fire	

Flood/Scour	
Hurricanes	
Impact Load	
Landslide/Washout	
Storm Surge/Wave Action	
Tsunami	
Other Hazards (please specify and rate according to their relative importance):	
Click on the box to add another hazard	
Click on the box to add another hazard	
Click on the box to add another hazard	

Question 4 (Resilience Tools and Software): What existing tools and software are used by your agency for assessing the performance and resilience of in-service bridges? Please use a scale of 1 (not used) to 5 (mostly used) for each software and/or tool on frequency of use.

Note: If needed, please use the last three boxes to specify other tools and software being used by your agency.

Software or tools	Rate from [1 – 5]
Hazus MH	
ShakeCast	
Finite element Modeling (FEM platform (please specify software in line below)	
UCINET	
Resilience Analysis and Planning Tool (RAPT)	
Other Software or tools (please specify and include frequency of use using the same scale):	
Click on the box to add another software/tool	

Click on the box to add another software/tool	
Click on the box to add another software/tool	

Question 5 (Hazard Maps): What hazard maps are used by your agency for assessing type and level of hazards? Please indicate the maps used on a scale of 1 (not used) to 5 (frequently used).

Note: If needed, please use the last three boxes to specify other hazard map(s) being used by your agency.

Hazard maps	Rate from [1 – 5]
US Geological Survey maps	
FEMA maps	
National Weather Service's (NWS) National Hurricane Center (NHC)	
Other Hazard maps (please specify and use same rating):	
Click on the box to add another hazard map	
Click on the box to add another hazard map	
Click on the box to add another hazard map	

Question 6 (Hazard Prediction): What are the three (3) most important issues or obstacles have your agency encountered regarding hazard prediction and recovery? Rank them based on most to least importance.

Note: Drag items to the boxes on the right. If needed, please use the last three boxes to specify other issue(s).

- ☐ **Budgetary issues**
- ☐ **Lack of resources**
- ☐ **Lack of relevant tools for specific hazard**
- ☐ **Lack damage prediction tools**
- ☐ *Click to add another issue*
- ☐ *Click to add another issue*
- ☐ *Click to add another issue*

Most Important		Least Important

Please provide a brief explanation for you ranking.

Question 7 (Structural Resilience): Do you quantify the structural resilience of bridges?

☐ Yes

☐ No

If Yes, Please select the most common approach used for quantifying the structural resilience of bridges during an extreme event in the preparation and recovery processes.

Note: If needed, please use the last two boxes to specify other approaches.

- ☐ Performance-based design
- ☐ Resilience-based design
- ☐ *Click on the box to add another approach*

If No, Please select the most common approach used for quantifying the structural response of bridges during an extreme event in the preparation and recovery processes.

Note: If needed, please use the last two boxes to specify other approaches.

- ☐ Force-based design
- ☐ Displacement-based design
- ☐ *Click on the box to add another approach*

Question 8 (Project Execution and recovery): In case of an extreme event(s) with widespread damage, how does your agency prioritize the recovery of affected bridges? Rank the three (3) most important criteria.

Note: Drag items to the boxes on the right. If needed, please use the last two boxes to specify other criteria.

Most Important		Least Important

- ☐ The affected bridges mostly contributing to business recovery
- ☐ Most deficient bridges
- ☐ The affected bridges on highly congested traffic areas
- ☐ Most bridges with life threatening damage
- ☐ Bridges that impact critical lifelines are prioritized (Communication network, electrical power, etc.)
- ☐ *Click to add another criterion*

☐ *Click to add another criterion*

Question 9 (Resilience Metrices): Are resilience metrices used by your agency?

☐ Yes

☐ No

If Yes, Please rank the following resilience metrices according to their relative importance:

Note: Please drag the items to arrange from most to least important. If needed, please specify other metrices in the last two boxes.

- ☐ **Robustness:** the ability of a given system to withstand/resist a given hazard with minimal or no functionality loss
- ☐ **Rapidity:** recovery time needed for a given system to bounce back to pre-hazard functionality
- ☐ **Redundancy:** the inherent components that keep system functionality even after the loss of part of the element
- ☐ **Resourcefulness:** ability to mobilize resources to recover after hazards, and
- ☐ **Regional societal impact:** economic and social impacts including safety and mobility
- ☐ *Click to add additional metrices*
- ☐ *Click to add additional metrices*

Question 10 (Functionality Loss): Select up to three (3) most common approaches used for determining the functionality loss of a bridge after an extreme event.

Note: If needed, please use the last two boxes to specify other approaches.

- ☐ **Send inspection crews**
- ☐ **Leverage use of drones or UAV (unmanned arial vehicles)**
- ☐ **Use of online tools such as ShakeCast**
- ☐ **Leverage damage prediction tools and software**
- ☐ **Leverage post-event analysis programs in conjunction with the reported damage**
- ☐ **In-situ load test**
- ☐ *Click on the box to add another approach*
- ☐ *Click on the box to add another approach*

Question 11 (Redundancy): How is redundancy incorporated in bridge design and repair during hazard preparedness and during recovery process after an extreme event? Please select the most common approaches.

Note: If needed, please use the last two boxes to specify other approaches.

- ☐ Bridges are considered part of redundant network where alternative routes are available during and after hazards
- ☐ Redundant structural elements by avoiding critical fracture elements
- ☐ Incorporating new materials such as shape memory alloy (SMA) and self-healing concrete.
- ☐ Incorporating new resilient systems such as self-centering or dynamically isolated systems
- ☐ Not currently addressed.
- ☐ *Click on the box to add another approach*
- ☐ *Click on the box to add another approach*

Question 12 (Rapidity): What are the three (3) most important factors in deciding whether a bridge will be replaced or repaired? Please rank the factors from the most important to the least important.

Note: Drag items to the boxes on the right. If needed, please use the last three boxes to specify other criteria.

Most Important		Least Important

- ☐ **Initial cost**
- ☐ **Life cycle cost**
- ☐ **Cost of replacement vs cost of repair**
- ☐ **Closure time**
- ☐ **Traffic safety and mobility**
- ☐ **Social impact**
- ☐ *Click to add another criterion*
- ☐ *Click to add another criterion*
- ☐ *Click to add another criterion*

Question 13 (Impeding Factors): How long does it take to conduct inspection following an event for one bridge assuming this bridge is prioritized for recovery?

- ☐ **One Day**
- ☐ **One Week**
- ☐ **Two weeks**
- ☐ **Less than a month**
- ☐ **Over one month**
- ☐ *Click to add a different inspection time*

Question 14 (Accelerated Construction and Repair): Are accelerated construction, repair and upgrade techniques considered in the decision-making process of hazard preparedness and recovery after an extreme event?

☐ Yes

☐ No

If Yes, Please provide insights of how ABC techniques are used.

Question 15 (Emerging Technologies): Do you leverage emerging technologies or advancements in data science in your decision-making regarding the pre-hazard preparedness and hazard recovery?

☐ Yes

☐ No

If Yes, Select the technology that your department/agency has used in practice.

Note: If needed, please use the last two boxes to specify other technologies.

- ☐ **Artificial Intelligence**
- ☐ **Robotics for Inspection**
- ☐ **Additive Construction (Additive manufacturing)**
- ☐ **Machine Learning**
- ☐ **Smart Materials**
- ☐ **Structural Health Monitoring**
- ☐ *Click on the box to add another technology*
- ☐ *Click on the box to add another technology*

We thank you for your time spent taking this survey.

Your response has been recorded.