IDAHO TRANSPORTATION DEPARTMENT

RESEARCH REPORT

Development of a Research Roadmap for ITD's Bridge Section

RP 312

By

Dustin Taylor, Arya Ebrahimpour, Ahmed Ibrahim, and Mustafa Mashal

Idaho State University and University of Idaho

Idaho Transportation Department

ITD Research Program, Planning and Development Services

Highways Division

June 2024

Disclaimer

This document is disseminated under the sponsorship of the Idaho Transportation Department and the United States Department of Transportation in the interest of information exchange. The State of Idaho and the United States Government assume no liability of its contents or use thereof.

The contents of this report reflect the view of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Idaho Transportation Department or the United States Department of Transportation.

The State of Idaho and the United States Government do not endorse products or manufacturers. Trademarks or manufacturers' names appear herein only because they are considered essential to the object of this document.

This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No. FHWA-ID-24-312	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Development of a Research Roadmap for ITD's Bridge Section		5. Report Date June 2024
		6. Performing Organization Code
7. Author(s) Dustin Taylor, Arya Ebrahimpour, Ahmed Ibrahim, and Mustafa Mashal		8. Performing Organization Report No.
9. Performing Organization Name and Address Idaho State University, Pocatello 921 South 8th Avenue Pocatello, Idaho 83209		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Idaho Transportation Department Highways Division, Planning and Development Services, Research Program PO Box 7129 Boise, ID 83707-7129		13. Type of Report and Period Covered Final Report 06/15/2023 – 06/15/2024
		14. Sponsoring Agency Code RP-312
15. Supplementary Notes Project performed in cooperation with the Idaho Transportation Department and Federal Highway Administration.		

16. Abstract

The Idaho Transportation Department (ITD) Bridge Section has been at the forefront of advancing bridge materials, design, construction, preservation, and inspection in Idaho through sponsored research. However, the department acknowledges the necessity of evolving from past ad hoc research requests to a more proactive and systematic approach. The aim is to align research efforts, ensuring they complement and build on each other for more impactful outcomes. To achieve this, the following steps were taken: (1) a detailed assessment of ITD's deficiently rated bridge inventory including individual element condition states, (2) a nation-wide department of transportation (DOT) funding and research survey, and (3) a comprehensive analysis of both past and ongoing DOT-financed research projects over the past 5 years. This information was used to supplement ITD's technical advisory committee expertise to generate a new list of high impact research queries tailored to Idaho's specific needs and interests. This list was then organized by priority with the top six being chosen for additional investigation. By adopting this proactive strategy, ITD aims to enhance the efficiency and effectiveness of its bridge-related research endeavors, ultimately contributing to safer and more resilient transportation infrastructure.

17. Key Words Bridges, Recommendations, Research Management, Research Projects, Highways, Planning and Forecasting		18. Distribution Statement Copies available from the ITD Research Program	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 239	22. Price None

Acknowledgments

The authors would like to thank the Idaho Transportation Department for supporting this research project. We would like to extend our thanks to the members of the Technical Advisory Committee, Darren LaMay, Mike Johnson, Ed Miltner, Dana Dietz, Scott Litchfield, Ned Parrish, and Amanda Laib for their assistance throughout the research process. Their guidance played a crucial role in shaping the direction of this study. We are also appreciative of Leonard Ruminski and Travis Butz for their vital expertise and feedback in the production and peer review of this research.

Technical Advisory Committee

Each research project is overseen by a Technical Advisory Committee (TAC), which is led by an Idaho Department of Transportation (ITD) project sponsor and project manager. The TAC is responsible for monitoring project progress, reviewing deliverables, ensuring that study objectives are met, and facilitating implementation of research recommendations, as appropriate. ITD's Research Program Manager appreciates the work of the following TAC members in guiding this research study.

- Project Sponsor: Michael Johnson
- Project Manager: Darren LaMay
- TAC Members: Dana Dietz, Scott Litchfield, Ned Parrish, Amanda Laib
- FHWA-Idaho Advisor: Ed Miltner

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AASHTO....................... American Association of State Highway and Transportation Officials

ABC .... Accelerated Bridge Construction

ADE .... Agency Developed Elements

AI .... Artificial Intelligence

ASR............................. Alkali Silica Reaction

BME .... Bridge Management Elements

BMS .... Bridge Management System

CC .... Conventional Concrete

CIP.............................. Cast-In-Place

CR .... Condition Rating

CS............................... Condition State

DIM .... Digital Information Management

DOT............................ Department of Transportation

FEA............................. Finite Element Analysis

FHWA......................... Federal Highway Administration

FLWA.......................... Fine Lightweight Aggregate

FRC............................. Fiber Reinforced Concrete

FRP............................. Fiber Reinforced Polymer

FT .... Freeze-Thaw

GGBS.......................... Granulated Blast-Furnace Slag

GPR .... Ground Penetrating Radar

HESC........................... High Early Strength Concrete

HMWM .... High Molecular Weight Methacrylate

HPC .... High Performance Concrete

HRWR......................... High Range Water Reducer

IC................................ Internal Curing

IC HPC .... Internally Cured High Performance Concrete

ICC............................... Internal Concrete Curing

IF................................ Infrared

ISU .... Idaho State University

KML............................. Keyhole Markup Language

LCC.............................. Low Cement Concrete

LCCA............................ Life Cycle Cost Analysis

LMC............................. Latex Modified Concrete

LMC-VE .... Very Early Strength Latex Modified Concrete

LP-HPC .... Low-Cracking High-Performance Concrete

LWA .... Lightweight Aggregate

LWFA........................... Lightweight Fine Aggregate

MASH.......................... Manual for Assessing Safety Hardware

MCTI .... Missouri Center for Transportation Innovation

MIRA........................... Microscopic Image-Based Rating Analysis

NBE............................. National Bridge Elements

NBI.............................. National Bridge Inventory

nHPC........................... Nano-engineered High-Performance Concrete

NP............................... Non-Proprietary

OPC............................. Ordinary Portland Cement

PA .... Presoaked Aggregate

PLC.............................. Portland Limestone Cement/Portland-Limestone Cement

PPC.............................. Polyester Polymer Concrete

PPCB .... Precast Pretensioned Concrete Beam

PRF.............................. Project Request Form

RAC............................. Research Advisory Committee

RBP .... Risk Based Prioritization

S&H............................. Structures and Hydraulics

SAP.............................. Superabsorbent Polymers

SCM .... Supplementary Cementitious Material

SRA............................... Shrinkage Reducing Admixtures

SSHC............................ Standard Specification for Highway Construction

TAC .... Technical Advisory Committee

TRB............................... Transportation Research Board

UAV.............................. Unmanned Aerial Vehicle

UAS .... Unmanned Aerial System

UHPC............................ Ultra-High Performance Concrete

UI .... University of Idaho

USDOT.......................... United States Department of Transportation

VTRC .... Virginia Transportation Research Council

WCSD........................... Weighted Condition State Distribution

List of State Department of Transportation Acronyms

ADOT........................... Arizona Department of Transportation

ALDOT.......................... Alabama Department of Transportation

ARDOT.......................... Arkansas Department of Transportation

Caltrans........................ California Department of Transportation

CDOT........................... Colorado Department of Transportation

CTDOT.......................... Connecticut Department of Transportation

DELDOT........................ Delaware Department of Transportation

DOT&PF .... Alaska Department of Transportation and Public Facilities

FDOT .... Florida Department of Transportation

GDOT .... Georgia Department of Transportation

HDOT .... Hawaii Department of Transportation

IDOT............................ Illinois Department of Transportation

INDOT .... Indiana Department of Transportation

Iowa DOT .... Iowa Department of Transportation

ITD .... Idaho Transportation Department

KDOT........................... Kansas Department of Transportation

KYTC............................ Kentucky Transportation Cabinet

LaDOTD .... Louisiana Department of Transportation and Development

MaDOT......................... Maryland Department of Transportation

MaineDOT.................... Maine Department of Transportation

MassDOT..................... Massachusetts Department of Transportation

MDOT.......................... Michigan Department of Transportation

MDT .... Montana Department of Transportation

MissDOT...................... Mississippi Department of Transportation

MnDOT........................ Minnesota Department of Transportation

MoDOT........................ Missouri Department of Transportation

NDOT .... Nebraska Department of Transportation

NCDOT .... North Carolina Department of Transportation

NDDOT .... North Dakota Department of Transportation

NHDOT .... New Hampshire Department of Transportation

NJDOT .... New Jersey Department of Transportation

NMDOT .... New Mexico Department of Transportation

NVDOT .... Nevada Department of Transportation

NYSDOT........................ New York State Department of Transportation

ODOT .... Ohio Department of Transportation

OKDOT .... Oklahoma Department of Transportation

ORDOT .... Oregon Department of Transportation

PennDOT...................... Pennsylvania Department of Transportation

RIDOT........................... Rhode Island Department of Transportation

SCDOT .... South Carolina Department of Transportation

SDDOT.......................... South Dakota Department of Transportation

TDOT .... Tennessee Department of Transportation

TxDOT .... Texas Department of Transportation

UDOT .... Utah Department of Transportation

VDOT............................ Virginia Department of Transportation

VTrans.......................... Vermont Agency of Transportation

WSDOT......................... Washington State Department of Transportation

WVDOT .... West Virginia Department of Transportation

WisDOT........................ Wisconsin Department of Transportation

WYDOT........................ Wyoming Department of Transportation

Executive Summary

To understand the Idaho Transportation Department (ITD) research needs, generate highly relevant research topics, and submit selected research topics for Research Advisory Committee (RAC) review, seven tasks were created: (1) conduct a kick-off meeting, (2) develop an understanding of ITD's bridge program, (3) determine Department of Transportation (DOT) bridge program best practices, (4) identify critical knowledge gaps, (5) determine and prioritize ITD bridge section research needs, (6) prepare draft research requests for selected research topics using ITD's research Project Request Forms (PRFs), and (7) prepare and present a final report. Each task, shown with a bold outline, along with their respective subtasks are shown in Figure ES.1. The following details each task and their conclusions, if applicable:

Task 1: Kick-off Meeting

A kick-off meeting was hosted on June 15th, 2023, and outlined (1) project members and introductions, (2) the project problem statement and research objectives, (3) team member survey results, (4) project tasks and deliverables, (5) research team member experience and research history, (6) project management and communication plan, and (7) project schedule.

Task 2: Develop an understanding of ITD's bridge program

To develop a better understanding of ITD's bridge program, an in-person meeting was held in Boise involving the project manager, ITD's research program manager, the project principal investigator, and a member of the research team. ITD bridge replacement and repair strategies, budget, research goals, research funding, and current projects were among the many topics discussed. In addition, the team gained access to inspection reports for Idaho's deficient bridges and a KML file that displays bridge locations in Google Earth.

Task 3: Determine DOT bridge program best practices and literature review

To determine DOT bridge program best practices, a comprehensive overview of current research efforts by DOTs in states other than Idaho was compiled. This included 857 recently concluded and ongoing projects focusing on bridge structures from the Transportation Research Board. In order to maintain a current and relevant project list, the search was confined to initiatives from within the last five years. Subsequently, these projects underwent three distinct filtering and ranking processes to produce a list of twenty-five projects closely aligning with ITD priorities and research preferences. The project rankings revealed that TAC members valued projects that focused on bridge decks and construction materials. In addition, organizing the twenty-five projects by categories suggested that bridge decks were the highest priority.

Task 4: Identify critical knowledge gaps

Identifying critical knowledge gaps involved a survey of out-of-state DOTs and a thorough examination of deficiently rated bridge elements within Idaho. The DOT survey focused on (1) bridge funding, (2) research priorities, and (3) research impacts which concluded that the bridge research focus areas varied significantly among DOTs, bridge deck and superstructure funding was the highest, and the average amount of funding in pooled funded projects was sixteen percent. The deficiently rated bridge element report outlined the current condition state of elements that make up deficient rated bridges and showed that substructure elements had the most severe conditions when accounting for element quantity within the total number of elements. In particular, reinforced concrete abutments, reinforced concrete pier walls, and reinforced concrete pile caps had the greatest condition state percentage in condition states three or four after being normalized with respect with element count. The report speculates that frequent repair and/or replacement of bridge decks, bearings, and rails prevents them from reaching more severe condition states.

Task 5: Determine and prioritize ITD bridge section research needs

The findings from tasks three and four were presented to the research team and ITD TAC members to guide the generation and ranking of research topics. The TAC and research team members provided suggestions to compile a list of twenty-three research topics closely aligned with ITD needs and priorities. After discussion and ranking, the top six projects were chosen. Lastly, a moderate literature review and Project Request Form (PRF) were prepared for each project. The six projects selected were: (1) Evaluate ITD's Bridge Deck Preservation Strategies, (2) Implementation of Internal Concrete Curing (ICC) to Enhance Concrete Performance, (3) Development of More Reliable Camber Prediction for Prestressed Deck Bulb-T girders, (4) Use of Non-Proprietary Ultra-High Performance Concrete in Idaho Bridges, (5) The Impacts of Type IL Cement on Bridge Structures, and (6) Bridge Deterioration Modeling.

Task 6: Prepare draft research requests for selected research topics using ITD's research PRFs

The project scope was determined based on literature reviews conducted in task five, guiding the creation of a PRF for each project addressing the following questions: (1) What problem would be addressed by this project? (2) How is ITD impacted by the problem? (3) What are the objectives of the proposed project? (4) Is the proposed work an extension of past research efforts? (5) What tasks do you envision? (6) What deliverables/outputs will be produced? (7) How will the research results be implemented? (8) How will the information and deliverables generated from the project be used to solve the problem? (9) How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas? And (10) What practical benefits will result from the work proposed, and how can they be measured?

Task 7: Prepare and present a final report

A final report was created detailing each task along with their applicable conclusions. All references are included along with sourced data and materials outlined in the appendices.

In March 2024, PRFs for the first two projects, (1) Evaluate ITD's Bridge Deck Preservation Strategies and (2) Implementation of Internal Concrete Curing (ICC) to Enhance Concrete Performance, were submitted to ITD's Research Advisory Committee (RAC) for possible approval for the following year. In the following year this project list will be revisited by ITD for further consideration.

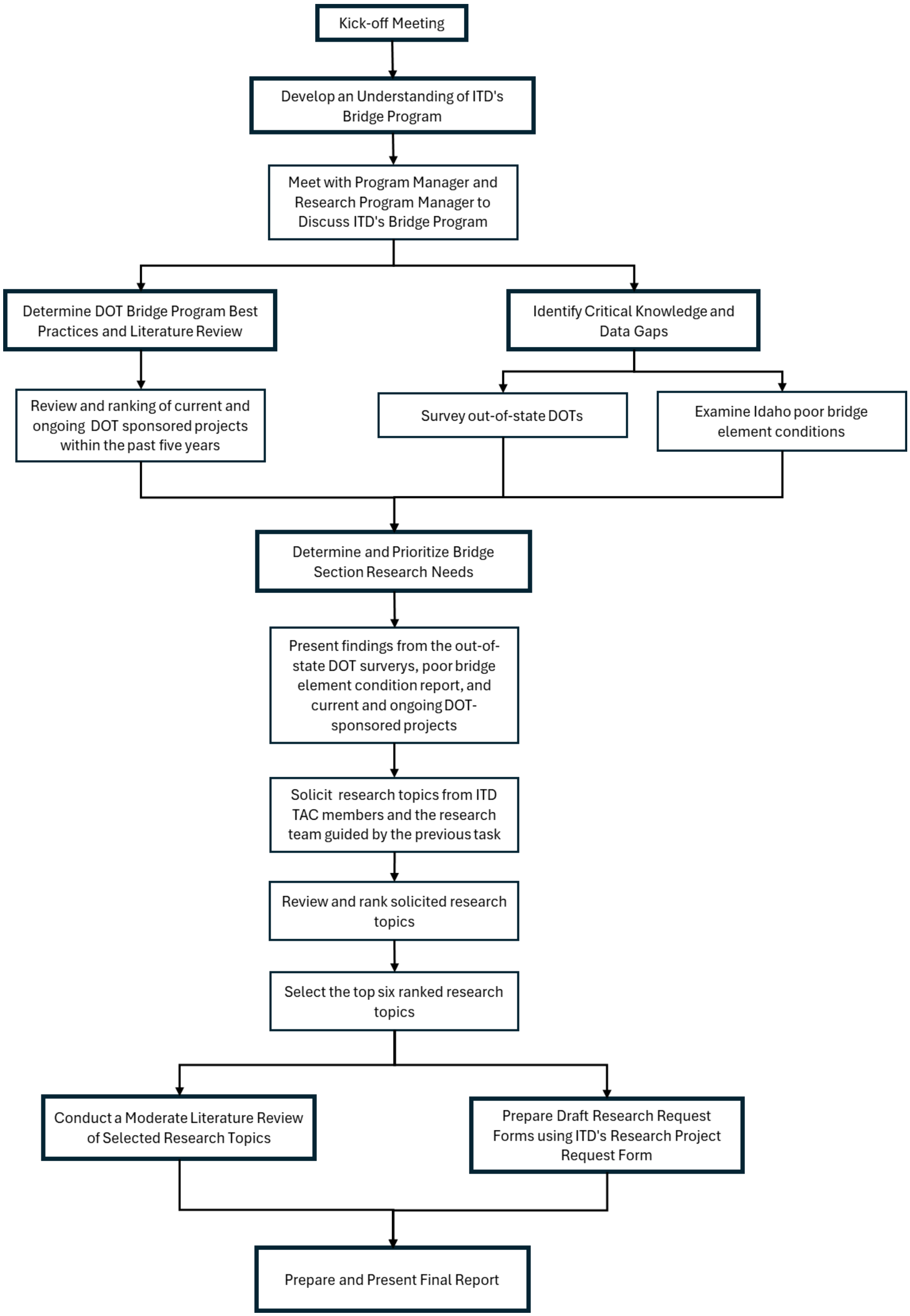


Figure ES.1 Project task and subtask flowchart.

1. Introduction

Problem Statement

The Idaho Transportation Department (ITD) Bridge Section has been at the forefront of advancing bridge materials, design, construction, preservation, and inspection in Idaho through sponsored research. However, the department acknowledges the necessity of evolving from past ad hoc research requests to a more proactive and systematic approach.

Objective

The aim of this project is to align research efforts, ensuring they complement and build on each other. Utilizing this new approach to research requests will facilitate risk mitigation by identifying and addressing potential risks and uncertainties more effectively, reducing the likelihood of project delays or failures. The overarching goal is to establish a clear and prioritized roadmap that aligns with ITD's mission of ensuring safety, mobility, and economic opportunity. To this end, the following steps were taken: (1) a comprehensive analysis of both past and ongoing DOT-financed research projects over the past 5 years, (2) a nation-wide department of transportation (DOT) funding and research survey, and (3) a detailed assessment of ITD's deficiently rated bridge inventory including individual element condition states. This information was used to supplement ITD's technical advisory committee expertise to generate a new list of high impact research queries tailored to Idaho's specific needs and interests. This list was then organized by priority with the top six being chosen for additional investigation.

Report Overview

This report starts by outlining the problem statement and objective of the project in the introduction. Then the methodology of the research selection process is explained, focusing on three explored avenues used to supplement ITD TAC member expertise and the solicitation and selection of research suggestions. These avenues were (1) DOT projects review and rankings, (2) DOT survey questionnaire, and (3) bridge element condition state examination. Next, comprehensive literature reviews for the 25 highest ranked out-of-state DOT projects and the six chosen research suggestions are presented. The Project Request Forms (PRFs) for the six selected projects are then shown detailing expected cost, duration, benefits, tasks, and objectives. Lastly, the summary and conclusions of the report are illustrated followed by cited works and a comprehensive appendix. The appendix includes: (A) DOT projects and their rankings, (B) DOT survey questionnaire responses, (C) Idaho deficient bridge general data, and (D) Idaho FHWA bridge element condition states.

2. Methodology and Literature Review

Methodology

To help guide the selection of future research projects, three avenues were investigated and presented to ITD's TAC members. These avenues include, (1) reviewing and ranking current ongoing and completed out-of-state Department of Transportation (DOT) sponsored projects from the past five years, (2) surveying out-of-state DOTs, and (3) examining the conditions of deficient bridges in Idaho. Once presented, research ideas were solicited from the research team and ITD TAC members. These research ideas were then discussed and ranked to develop a final short list of six highly relevant and agreed upon research topics. The following sections outline these steps in detail.

DOT projects Review and Ranking

To give ITD TAC members a comprehensive overview of ongoing research projects in DOTs beyond Idaho, 857 recently completed and ongoing projects relevant to bridge structures were sourced from the Transportation Research Board. To ensure a state-of-the-art project list, this search was limited to projects that have been started within the past five years. These projects were then subjected to three separate filtering efforts to create a project list of twenty-five projects that properly reflect ITD priorities and research interests. The following is an outline of these filtering efforts.

First Filtering Effort:

Due to the large amount of information associated with 857 projects, only the project titles and abstracts were referenced. Using these references, each of the research team's five members ranked all 857 projects from zero to five and an average for each project was calculated. Table 2.1 summarizes these project rankings, but a full project list with corresponding rankings can be seen in Appendix A.1. To narrow the list of projects, projects ranked below three were removed from the list, leaving 208 projects. To provide a general insight into ITD interests and priorities, Table 2.2 shows the category for projects rated four and above with the number of corresponding projects.

Table 2.1 Number of projects for each rating interval.

	Rated $0 \le X < 1$	Rated $1 \le X < 2$	Rated $2 \le X < 3$	Rated $3 \le X < 4$	Rated $4 \le X < 5$	Total
Number of Projects	112	296	241	168	40	857

Table 2.2 Number of projects in each category for projects rated 4 and above (some projects are included in more than one category).

Category	Number of Projects
Construction Materials	18
Bridge Management/Preservation	12
Inspection and Monitoring	1
Design and Load Rating	7
Rehabilitation and Repair	5
Bridge Decks	6
Total	49

Second Filtering Effort:

To narrow the second list of 208 projects, ITD TAC and research team members held two meetings. Instead of individually ranking each project, projects titles and abstracts were used to keep or remove projects after a brief discussion of project relevancy. This was done on a yes/no basis and can be seen in Appendix A.2. This filtering effort removed 129 projects leaving 79.

Third Filtering Effort:

The third and last filtering effort involved the entirety of the ITD TAC members and one member from the research team. Each of the remaining 79 projects were rated from zero to five to address the following two questions: (A) “Is the project applicable to ITD’s inventory and will the results of the project be likely to benefit ITD?” and (B) “Is there a need for ITD to perform a similar project, given that the research is completed or in progress elsewhere?”. Table 2.3 shows an average of these rankings for each category, however, the full scope of these rankings is provided in Appendix A.2.

Table 2.3 Average ranking by research category for questions A and B.

Category	Question A Average Ranking	Question B Average Ranking
Construction Materials	3.4	2.4
Bridge Management/Preservation	3.3	2.4
Inspection and Monitoring	3.2	2.3
Design and Load Rating	3.0	1.9
Rehabilitation and Repair	3.3	2.1
Bridge Decks	3.6	2.5
Misc.	3.6	2.2

Since question B is more relevant to future ITD research, the projects were then sorted by their question B rankings. The top 25 ranked projects are listed below:

1. Reduce Concrete Cracking Through Mix Design
2. Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements
3. Evaluate Bridge Deck Condition and Replacement Methods
4. Mitigation Strategies for Cracking in Concrete Bridge Decks
5. Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials
6. Implementation of Bridge Preservation Actions
7. Computer Vision Tools for Bridge Inspections and Reporting
8. Precast Pier System for Accelerated Bridge Construction in Idaho
9. Durability and Volumetric Stability of Non-Proprietary Ultra High-Performance Concrete Mixes Batched with Locally Sourced Materials
10. Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies
11. Evaluation of Bridge Rail Systems to Confirm AASHTO MASH Compliance
12. Testing and evaluation of energy absorbing panels for over-height collision impact protection
13. Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology
14. Significant Factors of Bridge Deterioration
15. Development of Deterioration Curves for Bridge Elements in Montana
16. Feasibility of 3D Scanning Technology for Bridge Inspection and Management
17. Vision-Based Detection of Bridge Damage Captured by Unmanned Aerial Vehicles
18. Aerial Infrared Scanning of Bridge Decks for Detecting and Mapping Delamination
19. Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands
20. Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking
21. Data-Driven Decision-Making Framework for Inspection of Bridge Decks
22. Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails
23. Accelerated Sulfate Attack Testing for Concrete
24. Repair and Strengthening of Bridge Girders using Ultra-High-Performance Concrete (UHPC)
25. Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete

A more comprehensive literature review was done for these projects and presented to the ITD TAC members to aid in research project creation and future project selections.

DOT Survey Questionnaire

A survey questionnaire was given by the ITD Research Program Manager to DOTs from all other 49 U.S. states in an attempt to gather further research project information. While the DOT projects review and rankings provide insight into specific DOT interests and project foci, the six questions constructed for this survey were created to gain a general overview of current and future research projects. Of the 49 states contacted, 21 replied. These were: Arizona, Arkansas, Colorado, Delaware, Iowa, Kentucky, Minnesota, Mississippi, Missouri, Montana, Nebraska, New Jersey, North Carolina, Oklahoma, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, and Wyoming. Some responses were incomplete or failed to answer the question directly. The following is a summary of these responses, with the complete survey response for all questions available in Appendix B.

Question 1: What are the focus areas or priority topics for current and future bridge research at your DOT? Why are you focusing your efforts in these areas?

While the responses for this question varied drastically, they can be organized into the following bridge-related categories: (1) design, (2) materials, (3) preservation/deterioration, (4) rail safety, (5) management, (6) repairs, (7) life-cycle cost, (8) digital information management (DIM)/digital delivery, (9) load rating, (10) deck overlays, (11) grease bearings, (12) concrete sealers, (13) culverts, (14) ice loading, (15) deck evaluation tools, (16) scour, and (17) construction speed. The two most common responses mentioned were (1) utilizing Ultra High-Performance Concrete (UHPC) for bridge joints, repair, and bridge deck overlays, and (2) various bridge preservation interests, including corrosion, concrete cracking, and evaluation techniques.

Question 2: What research completed in the last 5 years has had the most impact on your state DOT's bridge program? What was implemented and what benefits resulted from these projects?

A brief summary of each state's question two survey response is outlined in Table 2.4. Not all states answered this question adequately or at all, in which case a hyphen is displayed.

Table 2.4 Summary of question two survey responses.

Arizona	UHPC
Arkansas	Preservation, maintenance, and repair
Colorado	MASH rail
Delaware	Jointless bridges/overlay materials
Iowa	Accelerated bridge construction
Kentucky	-
Minnesota	UAS for bridge inspections
Mississippi	Prestressed beam camber
Missouri	None
Montana	Non-proprietary UHPC
Nebraska	Non-proprietary UHPC
New Jersey	Structural management, including deterioration curves
North Carolina	Bridge Repair
Oklahoma	Rebar corrosion
South Dakota	Unknown
Utah	Polyester polymer concrete (PPC) for bridge deck
Tennessee	Approach slab settlement
Texas	Bridge design
Vermont	-
Washington	Prestressed concrete pile columns
Wyoming	-

Question 3: What process does your bridge program follow for identifying and prioritizing bridge research needs?

Arizona, Delaware, Iowa, Minnesota, Nebraska, North Carolina, Oklahoma, Utah, Tennessee, Texas, and Washington identify and prioritize bridge research needs by collaboration with a combination of universities, internal committees, DOT staff, federal agencies, and industry professionals. Arkansas, Colorado, Mississippi, Missouri, South Dakota, and Wyoming prioritize research based on department needs and current issues.

Question 4: Please estimate the percentage of funding for current bridge research in your agency that is allocated to each of the following bridge component categories:

Many responses to this question were inadequate and removed from consideration. Figure 2.1 shows the average reported funding percentage for each category.

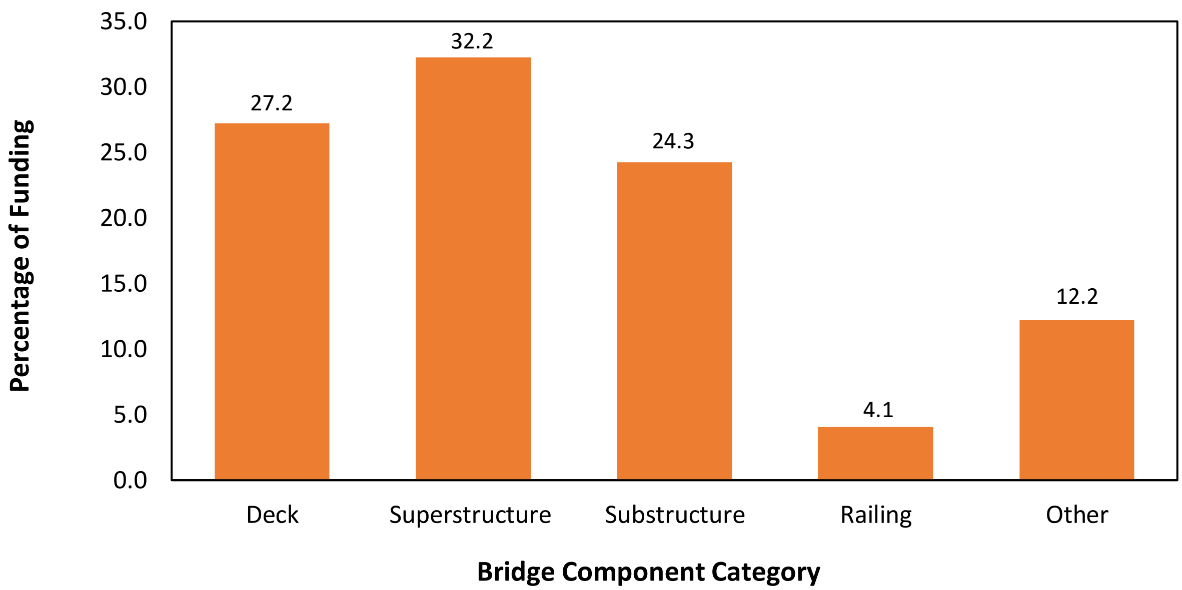


Figure 2.1 Average percentage of funding for each bridge component category.

Question 5: Please estimate the percentage of funding for current bridge research in your agency that is allocated to each of the following bridge program activities:

Many responses to this question were inadequate and removed from consideration. Figure 2.2 shows the average reported funding percentage for each activity.

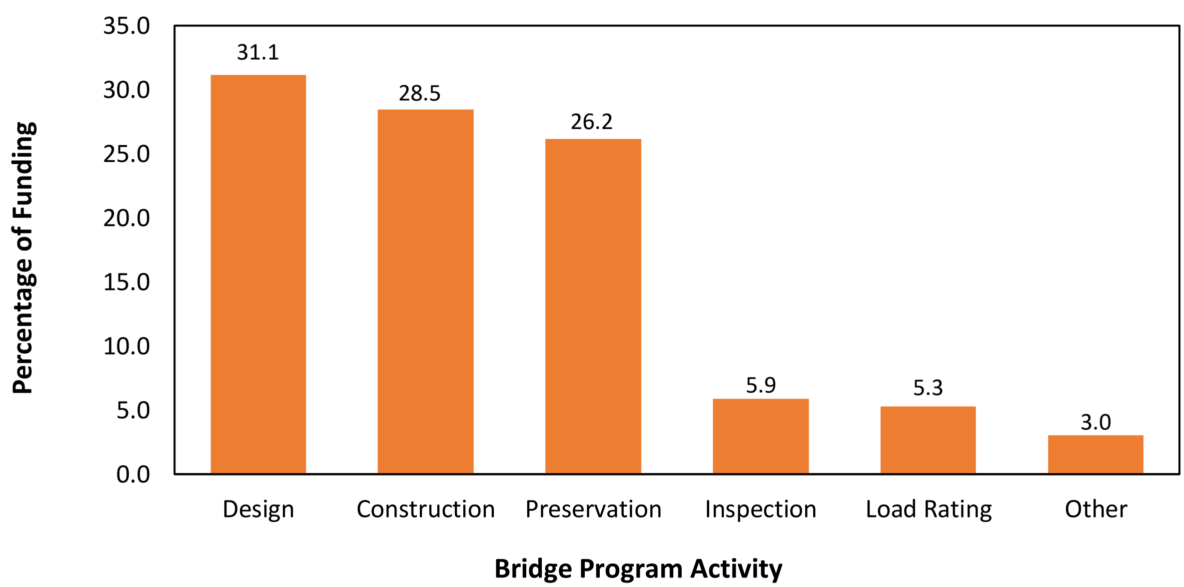


Figure 2.2 Average percentage of funding for each bridge program activity.

Question 6: What percentage of the current bridge research funding in your agency supports bridge-related Transportation Pooled Fund projects?

From those that provided specific percentages, the average percentage is approximately 15.7%. Figure 2.3 outlines the individual responses.

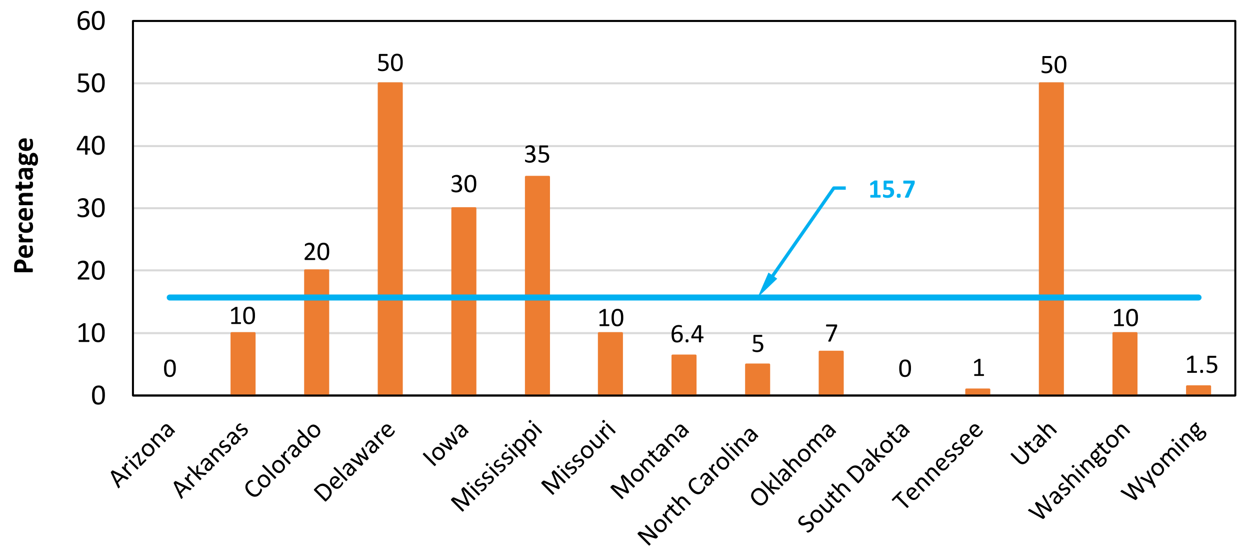


Figure 2.3 Percentage of research funding allocated to pooled fund projects.

Bridge Element Condition State Examination

Introduction

An element condition state analysis was conducted on bridge element data for bridges with a condition rating of four and below. This was done using data retrieved from the Federal Highway Administration (FHWA) website and ITD, shown in Appendices C and D. In this element condition state analysis, each bridge element across all bridges, with a condition rating of four or less, in Idaho were isolated and their combined corresponding condition states were totaled and normalized with respect to number of bridge elements and total quantity (e.g., area, length, or number). The aim is to gain insight into the current conditions of bridge elements and to use these findings to guide the selection of research topics for ITD.

Deficient Bridge/Culvert Classification

Deficient bridges or culverts are defined in this analysis to be bridges or culverts that meet one or more of the following requirements:

- Deck rating of 4 or less
- Superstructure rating of 4 or less
- Substructure rating of 4 or less
- Culvert Rating of 4 or less

Background

Condition States

Condition states are a rating system that provides two necessary types of information. It indicates the *severity* of the element by condition state rating and *extent* by reporting the distribution of the total element quantity among condition states. They range from 1 to 4 and are as follows:

Condition State 1: Good – No deterioration to minor deterioration
Condition State 2: Fair – Minor to moderate deterioration
Condition State 3: Poor – Moderate to severe deterioration
Condition State 4: Severe – Beyond the limits outlined in condition state 3 or constitutes a structural review

It should be noted that this scale has a low correlation with overall bridge deck, superstructure, and substructure ratings where the scale accounts for structural damage. While there is some relationship between the two scales at the extremes – e.g., if an element is rated 100 percent by quantity (e.g., area, length, or number) in Condition State 4, then that should correlate to a low overall bridge rating in that element category – it is not a direct relationship. While all condition states are being analyzed, there will be heavy emphasis on Condition States 3 and 4.

Element Identification System

National Bridge Elements (NBE) describe primary load carrying members; this will be the main focus of this bridge element condition state analysis. This element classification was created to only capture bridge members that are commonly used in bridge design. Keeping this element classification generic allowed The American Association of State Highway and Transportation Officials (AASHTO) to maintain flexibility, supporting varying maintenance practices, funding methodologies, and terminology among agencies (FHWA 2023). Each National Bridge Element, with consideration of the material it consists of, has a unique identification number, shown in Table 2.5. While there isn't a simple pattern associated with the given numbers and their corresponding elements, there are some general rules that can be applied. The three main bridge structure categories – deck, superstructure, and substructure – are broken down into the elements they consist of. Each category occupies a partitioned range from 0 to 300 and are organized in the following way:

- Deck elements (0-99)
- Superstructure elements (100-199)
- Substructure elements (200-299)

There are two other bridge elements that are not included within the three main bridge structure categories and are identified in the following way:

- Bridge Railing Elements (330-335)
- Bridge Bearing Elements (310-316)

Table 2.5 National Bridge Elements Identification Map (FHWA 2023)

	Steel	Prestressed Concrete	Reinforced Concrete	Timber	Masonry	Other
Deck						
Deck		**13**	12	31		*60*
Open Grid Deck	**28**					
Concrete Filled Grid Deck	29					
Corrugated / Orthotropic Deck	30					
Slab			38	54		*65*
Top Flange		15	16			
Superstructure						
Closed Web / Box Girder	102	104	105			106
Girder / Beam	107	109	110	111		*112*
Stringer	113	*115*	116	117		*118*
Truss	120			**135**		*136*
Arch	**141**	*143*	144	*146*	*145*	*142*
Main Cable	**147**					
Secondary Cable	**148**					*149*
Floor Beam	152	*154*	155	156		*157*
Pin, Pin and Hanger Assembly	161					
Gusset Plate	162					
Substructure						
Column	202	*204*	205	206		**203**
Column Tower (Trestle)	207			*208*		
Pier Wall			210	**212**	**213**	**211**
Abutment	219		215	216	217	218
Pile Cap / Footing			220			
Pile	225	*226*	**227**	228		*229*
Pier Cap	231	**233**	234	235		*236*
Culvert						
Culvert	240	**245**	241	*242*	*244*	**243**
Bridge Rail						
Bridge Rail	330		331	332	**334**	**333**
Bearing						
Elastomeric	310					
Movable	311					
Enclosed / Concealed	**312**					
Fixed	313					
Pot	**314**					
Disk	**315**					
Other	**316**					

[1]

[1] Cells with a red background indicate elements that are not found within any Idaho bridges, whereas cells with a yellow background show elements that are not among Idaho deficient bridges.

Although Bridge Management Elements (BME) and Agency Developed Elements (ADE) are not reviewed in this report, as relevant element classifications, they are worth mentioning. BME are recognized as joints, wearing surfaces, and protective systems and are shown in Table 2.6.

Table 2.6 Bridge Management Elements Identification Map (FHWA 2023)

Element	Units	Element Number
Joint		
Strip Seal	LF	300
Pourable	LF	301
Compression	LF	302
Assembly with Seal (Modular)	LF	303
Open	LF	304
Assembly without Seal	LF	305
Other	LF	306
Wearing Surfaces and Protective Coatings		
Wearing Surfaces	SF	510
Steel Protective Coating	SF	515
Concrete Protective Coating	SF	521

ADE are agency generated elements that conform to the same scaling system as the NBE and BME. The purpose of ADE is to create a more detailed element classification system that conforms to specific agency needs. Generally, they are constructed to differentiate between size, locations, and exposure of the same element.

Methodology

Data Acquisition and Composition

The first set of data for Idaho was taken from https://www.fhwa.dot.gov/bridge/nbi/element.cfm for 2023, as shown in Table 2.7 and Appendix D. In this example, state 16 is an identification number for Idaho, STRUCNUM is the structure identification number, EN is the element number, CS is condition state, and EPN is the element parent number. While the EPN is not used in this analysis, the column is maintained to provide an accurate representation of obtained data. The 2023 data set for bridge elements is the most recent available bridge element data set at the time of this analysis and the justification for its usage.

Table 2.7 Example of Data Obtained from the FHWA Website

STATE	STRUCNUM	EN	TOTALQTY	CS1	CS2	CS3	CS4	EPN
16	10000	12	87950	85547	2403	0	0	
16	10000	107	8610	8454	156	0	0	
16	10000	210	306	305	1	0	0	
16	10000	215	149	116	33	0	0	
16	10000	220	136	98	38	0	0	

In addition to the data set taken from the Federal Highway Administration's (FHWA) website, the Idaho Transportation Department (ITD) also supplied another set of data outlining all Idaho bridges and their identification number, intersecting feature, district, material, design, spans, maximum span length, length, year built, deck rating, superstructure rating, substructure rating, and culvert rating. An example is shown in Table 2.8.

Table 2.8 Example of Data Obtained from ITD

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
12805	SMA 7643; ECKERT RD	RIDENBAUGH CANAL	3	Concrete	Tee Beam	2	34	71	1954	6	5	5	N
12810	SMA 7643; ECKERT RD	BOISE RIVER (BARBER BR)	3	Concrete	Tee Beam	9	34	315	1954	7	6	5	N
12815	SH 21	MORES CR;LUCKY PEAK RES.	3	Steel Continuous	Truss-Deck	2	432	848	1953	6	5	5	N
17866	US 93	SALMON RIVER (WATTS BR.)	6	Steel Continuous	Stringer/ Girder	2	175	358	2009	7	7	8	N
14045	SH 34	LITTLE BLACKFOOT RIVER	5	Concrete	Frame	1	31	31	1979	6	6	7	N
11225	I 15 NBL	I 15B;S.POCATELLO IC	5	Prestressed Concrete	Stringer/ Girder	4	73	281	1965	8	6	7	N
11230	I 15 SBL	I 15B;S.POCATELLO IC	5	Prestressed Concrete	Stringer/ Girder	4	73	281	1965	8	6	7	N

<u>Data Limitations</u>

While this data gives the most recent element data reported to the FHWA, it is recognized that not all element data is strictly from 2023. In Idaho, bridge inspection reports are, at the longest, done in 2-year intervals. While these intervals can decrease depending on the condition of the bridge, it is possible that the data reported to the FHWA for Idaho is, at worst, 2 years old.

<u>Data Validation</u>

There were multiple levels of data validation for all sets of used data that can be characterized by the following:

The data set given by ITD was filtered to only show bridges with deficiently rated decks, substructures, or superstructures and deficiently rated culverts. This list was then counted to confirm the ITD-reported 186 total deficiently rated bridges and culverts.

The FHWA data set was cross referenced with list of deficiently rated bridges created from the data given by ITD to show only elements of deficiently rated bridges and culverts. This list was then filtered again to separate elements into deck, superstructure, and substructure categories. Lastly, the unique bridge IDs were counted to confirm 181 deficiently rated bridges and 5 deficiently rated culverts.

The results of this filtered data showed that, among deficiently rated bridges, there are 188 deck, 290 superstructure, 415 substructure, 5 culverts, 158 railing, and 117 bearing elements.

An unexpected finding of this data validation revealed that bridges 14925, 16545, 32240, and 32245 did not have reported superstructures. Upon further investigation, the corresponding bridge inspections reports also lacked superstructure elements; although, there was a reported overall superstructure rating. These bridges are classified as frame structures that have integrated superstructure and deck elements. These bridges can be seen in Figure 2.4, Figure 2.5, Figure 2.6, and Figure 2.7. It's worth noting that bridges 32240 and 32245 are sister bridges.

Figure 2.4 Bridge 14925, District 2.

Figure 2.5 Bridge 16545, District 4.

Figure 2.6 Bridge 32240, District 6.

Figure 2.7 Bridge 32245, District 6.

Feature Scaling

There are two types of feature scaling used in this analysis, feature scaling by bridge element quantity and total element count. The use of scaling by bridge element quantity allows for a fair assessment of differently sized bridge elements. The use of scaling by number of bridge elements scales these condition states based on the number of bridge elements in use. This ensures that outliers with a high percentage area of deficient condition states and low element counts don't skew the results. The assignment of feature scaling gives results where element degradation distribution and quantity are taken into consideration. For the bridge element quantity feature scaling, the total quantity distribution for each condition state of all bridge elements of the same type were totaled and divided by the total distribution. The following is the generalized mathematical approach used.

$$D_{E,r} = \frac{\sum_{i=1}^{N} d_{E,r,i}}{T_q}$$

Where,

- $D_{E,r}$ is the percent distribution of element *E* among Condition State, *r*, across all deficient bridges in Idaho.
- *i* is an index for unique deficient bridges in Idaho.
- *N* is the total number of deficient bridges in Idaho.
- $d_{E,r,i}$ is the quantity distribution for element *E* among Condition State *r* for bridge *i*.
- T_q is the total element quantity and can be represented by $\sum_{i=1}^{N} d_{E,i}$.

The feature scaling for bridge element count was done by applying a weight to each feature scaled element quantity. The weight applied was the percentage of number of elements when compared to the total number of bridge elements, the result of which ensures that the sum of all condition states across all elements is equal to one (or 100 as a percent). This can be thought of as an importance factor that is solely based on the relative number of deficient bridge elements. The following is the generalized mathematical approach used for the overall total feature scaling of data.

$$(D_{E,r})_{wa} = \left(\frac{N_E}{N}\right) D_{E,r}$$

Where,

- $(D_{E,r})_{wa}$ is the weighted average of $D_{E,r}$ with respect to element amount among element *E* and Condition State *r* across all deficient bridges in Idaho, or the weighted condition state distribution of an element (WCSD).

– N_E is the total number of elements *E* among all deficient bridges within Idaho.

– *N* is the total number of all deficient bridge elements in Idaho.

– $D_{E,r}$ is the percent distribution of element *E* among Condition State *r* across all deficient bridges in Idaho.

The following is an example using Element 104, Prestressed Concrete Closed Web/Box Girders. First, the FHWA data set is filtered to only show deficiently rated bridges and culverts that contain element 104. There are only three bridges (10920, 21035, and 23305) in this example that meet these qualifications, shown in Table 2.9.

Table 2.9 Filtered FHWA Data Set

STATE	STRUCNUM	EN	TOTALQTY	CS1	CS2	CS3	CS4	EPN
16	10920	104	1960	1578	377	5	0	0
16	21035	104	1500	254	579	667	0	0
16	23305	104	215	192	23	0	0	0

Then, the quantity condition state distribution can be calculated using the equations outlined in the feature scaling section and shown on the second line of Table 2.10.

Table 2.10 Element 104 Quantity Condition State Distribution

CS 1	CS 2	CS 3	CS 4	TOTAL
2024	979	672	0	3675
55.07	26.64	18.29	0.00	100.00
0.14	0.07	0.05	0.00	1173

The second line in Table 2.10 represents the area, length, or number percentage of the element that falls within each of the given condition states. In this case, 55.07 %, 26.64 %, 18.29 %, 0.00 % of elements 104 are distributed within Condition State 1, 2, 3, and 4, respectively.

The second line is again multiplied by a ratio of number of 104 elements over the total number of bridge elements. For this example, the weight coefficient is approximately 0.00256 with a total amount of bridge elements of 1173 (i.e., 3/1173 = 0.00256) and the number of deficient bridge elements containing element 104 being 3. Applying this weight gives 0.14 %, 0.07 %, 0.05 %, 0.00 %, for Condition State 1, 2, 3, and 4, respectively. This can be seen on the last line of Table 2.10.

Generation of ITD research topics

Once the weighted condition state distribution for all deficiently rated bridge elements has been calculated and graphed, they will be compared. This analysis emphasizes Condition State 3 and 4 to help identify elements that are most likely to need rehabilitation or replacement in the near future. To this end, an additional graph will be created to help summarize and compare only weighted condition state distributions for Condition State 3 and 4.

Once deficient elements have been identified, it will be suggested that research topics that tend to the construction, replacement, or preservation of these elements be explored.

Appendix E shows the weighted condition state percent distributions of each deficient bridge element.

Results

Individual element contributions can be seen in Appendix E.

The first graph, Figure 2.8, outlines the number of each element among deficient bridges in Idaho. Since the applied weights are based on the number of elements, this figure provides insights into how the weighted condition state percent distribution is calculated.

To make the results easier to interpret, the single-element weighted condition state percent distributions have been consolidated in Figure 2.9 and Figure 2.10. This is further expanded on in the conclusion.

The conclusion also references a lack of accurate element age data to compare elements with similar ages. To address this, the average element associated bridge age was calculated using the ITD and FHWA data sets and shown in Figure 2.11. It's important to note that this doesn't consider elements that have been repaired or rehabilitated since the bridges were initially built; however, it does offer perspective on why certain elements have high percentages within Condition State 3 and 4 regimes.

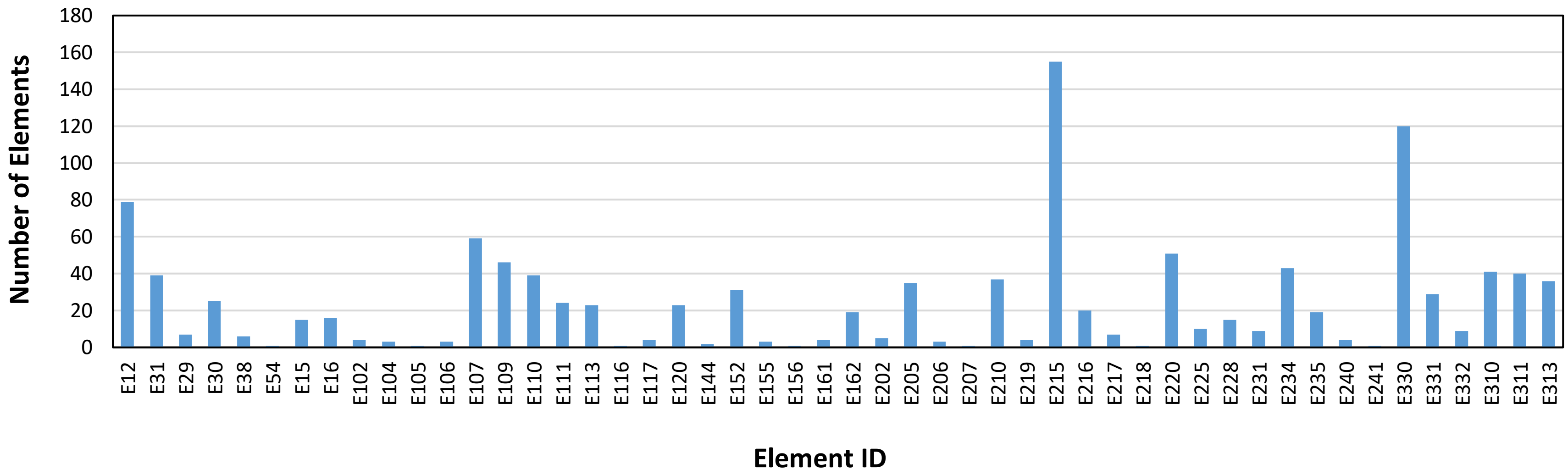


Figure 2.8 Total Number of Each Element Among Deficient Bridges in Idaho

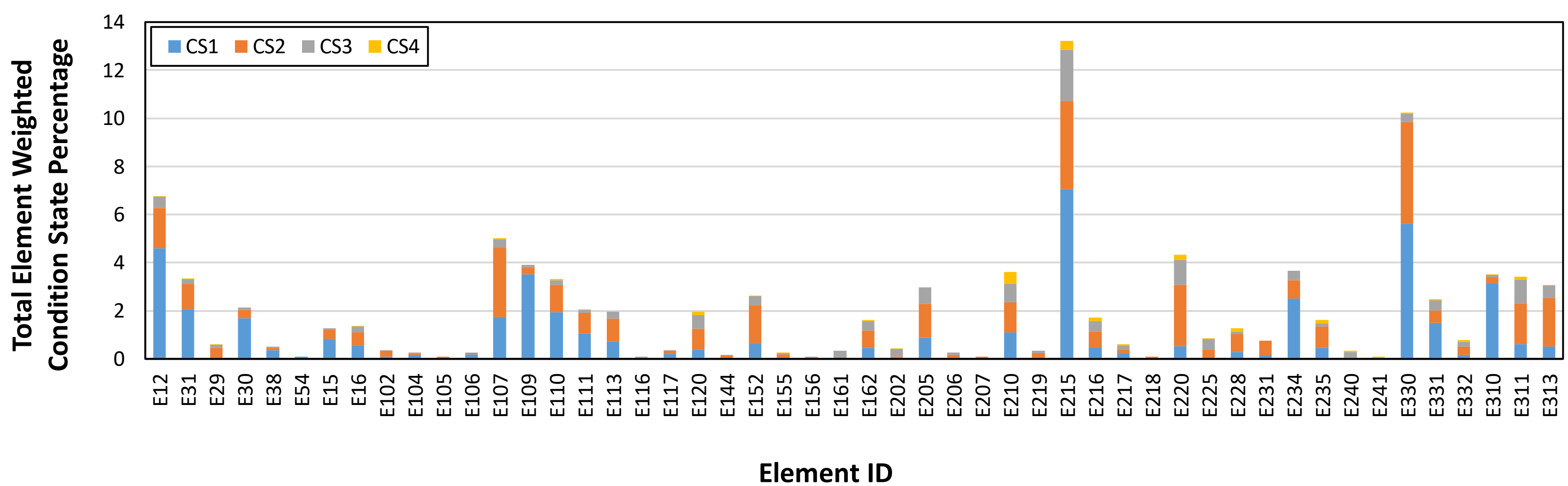


Figure 2.9 Weighted Condition State Distribution for all Elements in all States (Combines to 100%).

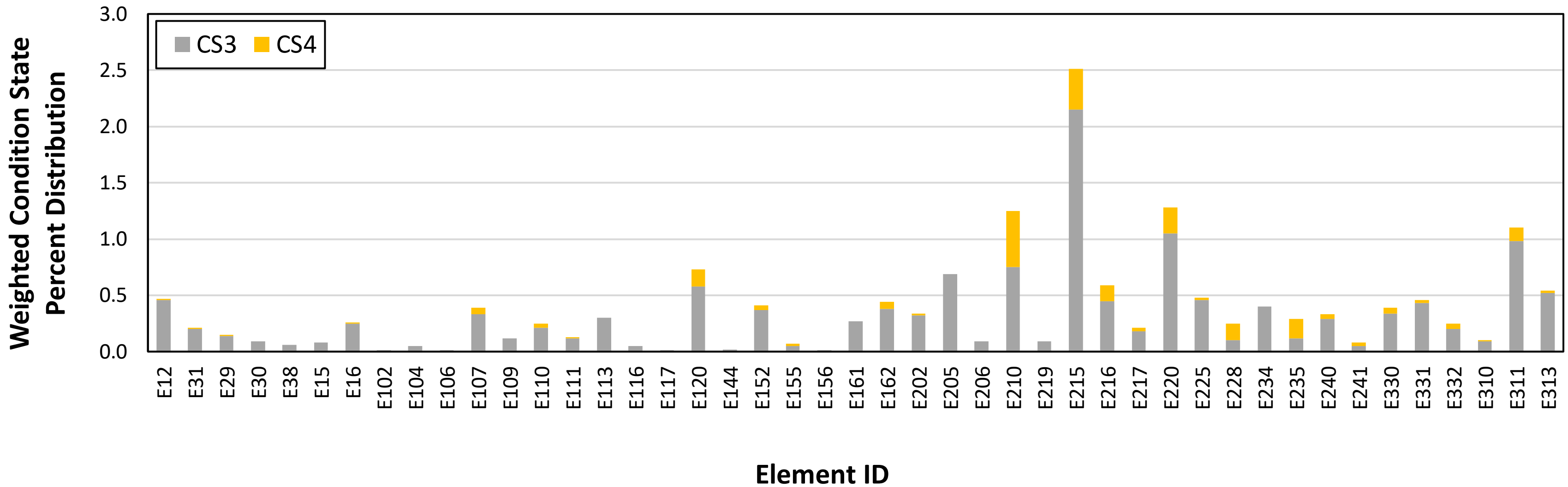


Figure 2.10 Weighted Condition State Percent Distribution for all Elements in CS3 and CS4.

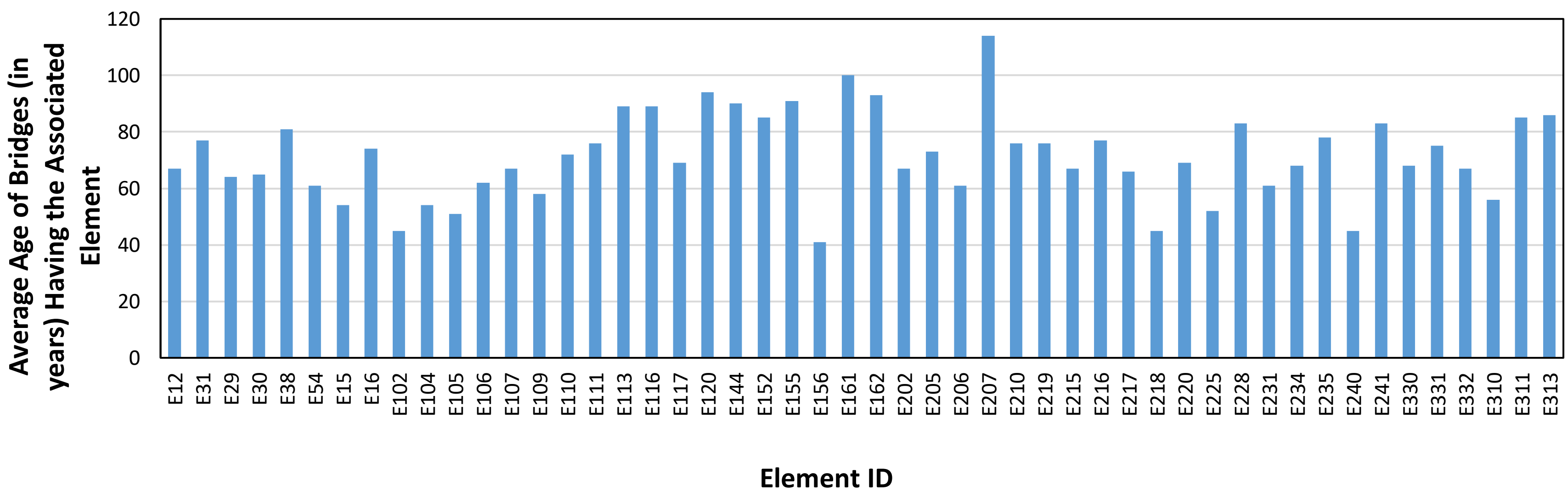


Figure 2.11 Average Age of Deficient Bridges Having the Associated Elements, as of 2023.

Conclusion

In order of descending element deficiency by element number weighted average, we have:

1. Element 215: Reinforced Concrete Abutment (No. of Bridges = 155)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 2.51%
2. Element 220: Reinforced Concrete Pile Cap / Footing (No. of Bridges = 51)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 1.28%
3. Element 210: Reinforced Concrete Pier Wall (No. of Bridges = 37)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 1.25%
4. Element 311: Movable Bearing (No. of Bridges = 40)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 1.10%
5. Element 120: Steel Truss (No. of Bridges = 23)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 0.73%
6. Element 205: Reinforced Concrete Column (No. of Bridges = 35)
    - Combined weighted condition state percent distribution for CS3 and CS4 of 0.69%

Element 215 was expected to be high-ranking within the final list since the number of elements are high, with 155 bridges utilizing this element. On the other hand, there are only 23 steel truss bridges, but the severity of the condition states has included them in the ranking above. A more detailed analysis, including a time component, specifically investigating these elements would need to be done to explore probable causes for deficient element ranking order.

Another point worth noting is that since element use duration was not included, the results in Figure 2.9 and Figure 2.10 are blind to instances where an element has been replaced or rehabilitated during the lifespan of a bridge. This being the case, bridge deck and bearing elements are generally of higher condition and quality than that of elements whose use durations are higher and get replaced or rehabilitated less often. This can be plainly seen in Figure 2.10, where the deck and bearing elements represent a smaller total then superstructure and substructure elements.

To avoid confusion, Figure 2.10 does not compare element longevity or effectiveness, and only interprets element conditions and quantities as they are now. Since time wasn't a component of this analysis, a more accurate interpretation of this data would be that the elements shown in Figure 2.10 and ranked in the beginning of this conclusion will need to be replaced soon. It is suggested that since funding will be used to rehabilitate or replace these elements in the near future, a research topic that facilitates this endeavor could save money, time, or increase the performance of these newly rehabilitated elements.

Literature Review

This section outlines the two literature reviews done to supplement the selection of research projects. The first literature review investigates the top twenty-five ranked DOT projects used to provide ITD TAC members with insights into research being performed by other state DOTS. This literature review, a bridge element condition report, and a DOT survey was then utilized to create a list of research ideas generated by the ITD TAC members. A second preliminary literature review was then conducted focusing on the top six ranked research ideas from this list.

Top Twenty-Five Ranked DOT Projects

1. Reduce Concrete Cracking Through Mix Design

   https://rip.trb.org/View/2083739

   Expected Completion Date: 12.31.2025

   Abstract Summary:

   The New Hampshire Department of Transportation (NHDOT) is sponsoring a project, being performed by the University of New Hampshire, to address early shrinkage concrete cracking by manipulating mix design. Cracking during construction affects long-term condition and overall performance for any structure exposed to road elements that can permeate throughout the material, including salts and moisture. NHDOT aims to develop a mix design more resistant to this permeation and resulting corrosion and deterioration by reducing this initial cracking. This could result in exposed decks and other, more economic, construction methods to be considered as a more viable option for bridge maintenance. In pursuit of this, NHDOT plans to apply these new design mixes to stand alone concrete structures, such as sidewalks and concrete slabs, to test and observe performance.

2. Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements

   https://rip.trb.org/View/2059153

   Expected Completion Date: 10.31.2025

   Abstract Summary:

   The Virginia Department of Transportation (VDOT) is sponsoring and performing a project to address issues with their alkali-silica reaction (ASR) guidelines for concrete. Since the 2020 Virginia Road and Bridge Specifications rely on the withdrawn ASTM C227, Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations, the ASR provisions must be updated. In pursuit of this, VDOT intends to adjust their ASR reliant standards to evaluate alkali content of concrete as a whole, rather than just cement. To this end, VDOT must develop a new alkali-silica test method that successfully evaluates total concrete loading to acceptable levels in pursuit of safely extending the service life of Virginia bridges.

3. Evaluate Bridge Deck Condition and Replacement Methods

https://rip.trb.org/View/2135463

Expected Completion Date: 03.31.2026

Abstract Summary:

The Texas Department of Transportation (TxDOT) is sponsoring a project, being performed by the Texas A&M Transportation Institute, to address bridge deck aging. Many Texas bridges have far exceeded their intended service life and are starting to show signs of failure in the form of deck soffit cracking. Since many of these bridges have superstructures and substructures in generally good conditions, TxDOT aims to develop streamlined deck assessment and replacement strategies, in an effort to reduce the associated costs. These streamlined procedures assist engineers in making decisions about emergency repairs, regular repairs, deck overlay, and deck replacement.

4. Mitigation Strategies for Cracking in Concrete Bridge Decks

https://rip.trb.org/View/1895367

Expected Completion Date: 03.01.2024

Abstract Summary:

The Maine Department of Transportation (MaineDOT) has recognized the need for concrete cracking investigation and prevention through prior research titled "Concrete Systems for a 100-Year Design Life". As the title suggests, the main objective of this research was to develop exceptionally durable concrete, utilizing available constituents, that are suitable for 100-year design life structures in typical New England exposure conditions. To further this goal, they have sponsored the University of Maine to continue research into concrete cracking mitigation strategies by exploring the effects of variety of aggregate grades, fibers, and differential temperatures. During this process the research team intends to include considerations for the impact on durability and mechanical properties.

5. Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials

https://rip.trb.org/View/1948643

Expected Completion Date: Unknown

Abstract Summary:

The New Mexico Department of Transportation (NMDOT) requires a minimum of 20%, by mass, class F fly ash for almost all concrete used in state projects to reduce alkali-silica reactions (ASR) of commonly used aggregate by the state. Since class F fly ash is becoming increasingly difficult to procure and its future availability is uncertain, NMDOT has sponsored research being performed by Louisiana State University to test alternative supplementary cementitious materials (SCMs). Two SCMs, natural pozzolan mined from within the state and metakaolin, have been selected by NMDOT to be thoroughly tested to ensure minimum workability, strength, and durability characteristics. Once tested and ASR mitigation capabilities of the selected SCMs have been validated, the project aims to develop utilization guidelines to limit unnecessary use; this will extend the availability of these new SCM sources.

6. Implementation of Bridge Preservation Actions

https://rip.trb.org/View/1957059

Expected Completion Date:

Abstract Summary: 12.08.2024

The purpose of this project is to implement workshops for state DOTs and applicable local public agencies to apply bridge preservation practices supported by AAHSTO publications: (1) Guide to Bridge Preservation Actions (Published July 2021) and (2) Guide to Preservation of Highway Bridge Decks (pending publication). To achieve this, the following tasks will be completed: (1) a draft outline of content, format, and delivery method, (2) submittal of a task report for task 1 documentation, (3) list and document necessary materials, (4) test one pilot instructor-led workshop at a state department of transportation (DOT), (5) collect and implement pilot workshop participant feedback, (6) create recorded web-based modules, (7) determine number of maximum workshops permitted by funding supplemented with locations and dates, (8) conduct remaining in-person workshops, and (9) submit final deliverables.

7. Computer Vision Tools for Bridge Inspections and Reporting

https://rip.trb.org/View/2190087

Expected Completion Date: 01.31.2025

Abstract Summary:

The Alaska Department of Transportation & Public Facilities (DOT&PF) is sponsoring a project being performed by the University of South Dakota. The project aims to incorporate the use of artificial intelligence (AI) into a mobile-based image processing program. Through this incorporation, the research aims to assist bridge inspections and element condition assessments by developing AI supported tools to evaluate bridges in a more accurate, consistent, and rapid manner. Ideally, this project will allow bridge inspectors to identify and measure damage and defects by taking only a picture and running it through the AI assisted image processing program. Since DOT&PF is responsible for inspecting and reporting roughly 1000 bridges to the FHWA, they intend to save time and money by incorporating this research into their bridge inspection process.

8. Precast Pier System for Accelerated Bridge Construction in Idaho

https://rip.trb.org/View/1602647

Completion Date: 06.30.2021

Abstract Summary:

Sponsored by the Idaho Transportation Department (ITD), and performed by Idaho State University, this project tested an ITD-developed precast concrete pier system utilizing new connection methods designed to support moments that develop at column connections. These new connections were designed to reduce construction time and demonstrate superior performance during seismic events by placing structural tubes filled with concrete in plastic hinge locations between pier columns and footings and pier columns and pier caps. In depth testing was done with nearly identical cast-in-place and precast cantilever pier columns to compare and contrast seismic performance. It was found that the precast columns could withstand more drift cycles (16), higher deflections (9.6 inches), a higher moment capacity (267.8 kip-ft), and dissipated more energy (1025 kJ). This is in contrast with the cast-in-place pier column which exhibited a maximum of 13 drift cycles, a maximum of 7.7-inch deflection, a 245.7 kip-ft moment capacity, and energy dissipation of 456 kJ. These results have facilitated the incorporation of this new pier column connection design in a new bridge within a seismic zone.

9. Durability and Volumetric Stability of Non-Proprietary Ultra High Performance Concrete Mixes Batched with Locally Sourced Materials

https://rip.trb.org/View/2046774

Expected Completion Date: 07.31.2024

Abstract Summary:

North Dakota State University is conducting research pertaining to the creation of non-proprietary (NP) ultra-high performance concrete (UHPC). This endeavor is expected to significantly reduce the cost of UHPC applications, including bridge closure pours, by utilizing locally sources materials for the newly developed design mix. Since these materials are found within close proximity, transportation and acquisition costs will be much lower. To maintain traditional UHPC performance, this newly developed NP UHPC will need to undergo a series of tests to examine its durability and volume stability.

10. Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies

https://rip.trb.org/View/2071679

Expected Completion Date: Unknown

Abstract Summary:

To aid in the development of protocols for deck preservation strategies, Federal Highway Administration (FHWA) is sponsoring a project being performed by Infratek Solutions in New Jersey. More specifically, the project seeks to develop an early-age vulnerability detection and quantification system. This is intended to be accomplished by separating tasks into two stages. Stage one will be data collection on specified bridges using a specialized vehicle to measure bridge cracks and deck permeability. Once this is done the collected data will be organized to determine which bridges are a maintenance priority. Stage two will focus on validating data collected from stage one by inspection report comparisons and utilizing results to develop data-driven bridge deck preservation strategies at different bridge deck service life times.

11. Evaluation of Bridge Rail Systems to Confirm AASHTO MASH Compliance

https://rip.trb.org/View/1467502

Completion Date: 06.01.2022

Abstract Summary:

In 2016 the AASHTO technical committee adopted a new manual for assessing roadside safety features called the Manual for Assessing Safety Hardware (MASH). Since many bridge rail systems were built prior to this adaptation, there is a need to reevaluate these bridge railing systems to MASH standards. This research aims to update the existing AASHTO LRFD Bridge Design Manual and the AASHTO Roadside Design Guide to be MASH compliant.

12. Testing and evaluation of energy absorbing panels for over-height collision impact protection

https://rip.trb.org/View/2096581

Expected Completion Date: 09.30.2025

Abstract Summary:

Since vehicle collisions are among the top causes of bridge failure or collapse, the following seven states have contributed to a pooled funded project to test, install, and evaluate a newly developed prototype system aimed at addressing this issue: (1) Arkansas, (2) Georgia, (3) Louisiana, (4) New Jersey, (5) New York, (6) Oklahoma, and (7) Virginia. The prototype is designed to dissipate vehicle kinetic energy by crushing and deforming an internal honeycomb lattice that is mounted on an exterior girder face. The new system has been tested by theoretical modeling and now must be physically tested prior to installation and use. The focus of this project is to identify optimal installation means, verify the system's effectiveness, and validate the theoretical modeling via comprehensive testing.

13. Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology

https://www.ksdot.gov/Assets/wwwksdotorg/bureaus/KdotLib/2020/FHWA-KS-20-04_Summary.pdf

Completion Date: 09.30.2020

Abstract Summary:

Performed by the University of Kansas and sponsored by the Federal Highway Administration (FHWA), this research explores utilization of internal curing in conjunction with supplementary cementitious materials (SCMs) and Low-Cracking High-Performance Concrete (LC-HPC) specifications to reduce the cracking in bridge decks and increase service life. To achieve this, practical mixture proportioning procedures LC-HPC and fine lightweight aggregate (FLWA) handling and storage were identified and tested. In addition, four bridge decks from Minnesota, that adopted the specifications created by this research, were monitored using crack surveys for two years. Of the four bridges, one bridge deck was not completed up to specifications due to FLWA moisture that resulted in batch rejections. These rejections led to insufficient material for the completion of the bridge deck. The bridges that used the specifications were found to have low crack densities when compared with control bridge decks after being normalized for age.

14. Significant Factors of Bridge Deterioration

https://rip.trb.org/View/1983704

Expected Completion Date: 10.31.2024

Abstract Summary:

Sponsored by the Montana Department of Transportation (MDT) and performed by Montana State University, this research intends to address challenges encountered while developing Montana-specific bridge element deterioration curves. These challenges mainly involve identifying variables that contribute to bridge element deterioration, such as climate, maximum traffic weight, construction, maintenance, and bridge management practices, problems associated with the limits of the bridge element rating scale, and lack of sufficient data for substandard ratings. Once adequate solutions have been found, the results are to be incorporated into the existing deterioration modeling to improve forecasting accuracy.

15. Development of Deterioration Curves for Bridge Elements in Montana

https://trid.trb.org/view/2078641

Completion Date: 10.01.2022

Abstract Summary:

Montana State University completed research, sponsored by the Montana Department of Transportation (MDT), to develop bridge element deterioration curves meant to be integrated with bridge management software developed by AASHTO (BrM). Deterioration curves were developed for six bridge elements that reflected MDT maintenance priorities, including steel girders, concrete abutments, steel culverts, reinforced concrete decks, prestressed concrete girders, and concrete culverts. The modeling results were validated through MDT bridge engineer experience. Variations in deterioration models from the five different maintenance districts within Montana were also investigated (Montana Department of Transportation 2022).

16. Feasibility of 3D Scanning Technology for Bridge Inspection and Management

https://rip.trb.org/View/2057908

Expected Completion Date: 04.08.2025

Abstract Summary:

The Indiana Department of Transportation (INDOT) has sponsored research, being performed by Purdue University, to develop an automated framework that analyzes three-dimensional scanned data to assess conditions and capacities of bridge members.

17. Vision-Based Detection of Bridge Damage Captured by Unmanned Aerial Vehicles

https://rip.trb.org/View/1992939

Expected Completion Date: 06.30.2024

Abstract Summary:

Being performed by the University of Maine and sponsored by the Rhode Island Department of Transportation (RIDOT), this research aims to provide a more consistent alternative to bridge inspection through the use of unmanned arial vehicles (UAVs). These UAVs will be equipped to scan bridges with enough data to create a navigable three-dimensional model. In addition, artificial intelligence (AI) can be implemented to assess and identify bridge element damage.

18. Aerial Infrared Scanning of Bridge Decks for Detecting and Mapping Delamination

https://rip.trb.org/View/2190082

Completion Date: 03.31.2023

Abstract Summary:

This research was performed by Infrasense Inc. and sponsored by the Federal Highway Administration (FHWA). To assess the potential for deck condition evaluations done by aerial imaging, Infrasense collected bridge condition data along Alaska's Parks Highway using aerial infrared thermography (aerial IF) in conjunction with visual imaging data using a fixed wing aircraft. These results were compared with data taken from visual inspections and a return-on-investment analysis was done. Of the 69 bridge decks evaluated, 12 were chosen to compare results with ground truth evaluations using chain drag sounding. This showed a maximum of 2% variance in evaluation quantities between the two methodologies. In addition, the economic analysis estimated a 223% return-on-investment and an annual reduction of 125 hours to traffic for inspections.

19. Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands

https://rip.trb.org/View/2087372

Expected Completion Date: 12.31.2026

Abstract Summary:

This research, performed by Virginia State University and sponsored by the Virginia Department of Transportation (VDOT), aims to address end beam cracking in prestressed beams by developing new details. These details will contain new tables and drawings for welded grid reinforcement that can be used for design, bidding, and construction. Results from this research should improve guidance for increasing stress limitations for beam ends with debonded and/or draped strands. This guidance will be based on a comprehensive literature review, DOT surveys of current practices, finite element modeling, and testing.

20. Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking

https://rip.trb.org/View/1589400

Completion Date: 10.31.2020

Abstract Summary:

Sponsored by the Wisconsin Department of Transportation (WisDOT) and performed by CTL GROUP, this research aims to develop WisDOT specific internal curing implementation, tools, and specification guidance by documenting and evaluating the use of this curing method for concrete in bridge decks. Over the last twenty years there has been a push to implement high performance concrete for bridge decks to utilize its superior strength and performance. Recently, this concrete has been found to be highly susceptible to early age cracking due to its low water to cement ratio. To address this, internal curing has been employed to offsets moisture loss from hydration by providing moisture through aggregate, fibers, or polymers. It was found that volumetric stability was improved when the water-to-cement ratio was 0.36, but there were negligible effects when the water-to-cement ratio was 0.45. It was then concluded that the service life of bridge decks can be extended by using internally cured concrete. Recommendations for internally cured concrete implementation for the WisDOT Specifications were provided.

21. Data-Driven Decision-Making Framework for Inspection of Bridge Decks

https://rip.trb.org/View/1841352

Expected Completion Date: 01.31.2023

Abstract Summary:

This project is sponsored and performed by the Virginia Transportation Research Council (VTRC) and intends to expand on current bridge inspections, as regulated by the National Bridge Inspection Standards. The main focus of this project is to investigate alternative inspection means through the utilization of advanced technology. This process should increase the effectiveness of traditional inspections by providing additional consistent bridge condition data that can be used to guide maintenance decisions.

22. Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails

https://rip.trb.org/View/2201940

Expected Completion Date: 12.31.2024

Abstract Summary:

The Nebraska Department of Transportation (NDOT) has sponsored a project to validate and expand on research done by the University of Nebraska. In 2021, the University of Nebraska started research to develop a low-cement concrete design mix for bridge decks and rails that required less cementitious material while maintaining similar characteristics to previously used concrete design mixes. While this design mix was completed, its workability curing time, bleed rate, and air entrainment were suboptimal. This project intends to address these issues, in addition to validating mechanical and durability properties, by applying internal curing and liquid fly ash.

23. Accelerated Sulfate Attack Testing for Concrete

https://rip.trb.org/View/1948644

Expected Completion Date: Unknown

Abstract Summary:

The University Transportation Centers Program is sponsoring a project being performed by New Mexico State University to develop accurate and repeatable sulfate attack testing for concrete. ASTM C1012, Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution, is currently used to test cements for sulfate resistance, but can require measurement that take 18 months to acquire. In light of this, the project seeks to develop a testing method that provides the same results in a much shorter time frame. To achieve this, the project starts with a comprehensive literature review, then studies the effects of supplementary cementitious materials (SCMs) on sulfate attacks, and looks into alternative testing methods. Results from this will be followed up with experimental testing and validation.

24. Repair and Strengthening of Bridge Girders using Ultra-High-Performance Concrete (UHPC)

https://rip.trb.org/view/1942731

Expected Completion Date: 05.31.2024

Abstract Summary:

The Nebraska Department of Transportation (NDOT) is sponsoring a project being performed by the University of Nebraska to investigate the utilization of UHPC for strengthening bridge girders. Two previous studies, also sponsored by NDOT, aimed to reduce the cost of UHPC and develop guidelines for cast-in-place (CIP) implementation. Through this research, it was deemed feasible to also apply the superior performance of UHPC to bridge girder repair and strengthening.

25. Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete

https://rip.trb.org/View/2083726

Expected Completion Date: 04.30.2025

Abstract Summary:

Sponsored by the Indiana Department of Transportation (INDOT) and performed by Purdue University, this research addressed the four following objectives: (1) evaluate nanosilica admixture utilization impacts on air-void properties of concrete used for bridges, (2) test the significance of air-void characteristics on the freeze-thaw resistance of concrete, (3) explore production method variation consequences on concrete durability, and (4) investigate the influence of non-traditional air entrainment products in concretes with nanosilica admixtures.

List of Twenty-Three Solicited Research Topics

Using the (1) review and rank of current ongoing and completed out-of-state Department of Transportation (DOT) sponsored projects from the past five years, (2) survey out-of-state DOTs, and (3) examination of element condition states for deficient rated bridges in Idaho, a list of twenty-three highly relevant research topics were generated from the ITD TAC members and project research team. In order of rank, these projects are as follows:

1. Evaluate ITD's Bridge Deck Preservation Strategies.
2. Implementation of Internal Concrete Curing (ICC) to Enhance Concrete Performance.
3. Development of More Reliable Camber Prediction for Prestressed Deck Bulb-T girders.
4. Evaluation of Alternative Thin Deck Overlay Materials for Newly Constructed Bridges with Deck Bulb-T Girders.
5. Use of Non-Proprietary Ultra-High Performance Concrete in Idaho Bridges.
6. The Impacts of Type IL Cement on Bridge Structures.
7. Bridge Deterioration Modeling.
8. Increasing the Life of Concrete Bridge Components Using Protective Coatings.
9. Load Ratings of Deteriorated Bridges.
10. Creation of a Prioritization Program for all Deficiently Rated Bridges Within Idaho.
11. Alternative Materials for Deck Reinforcement.
12. Revaluation of Idaho's Legal Vehicles.
13. The use of Advanced Materials in Idaho Bridges.
14. Utilization of Lightweight Concrete in Prestressed Beams.
15. Utilization of FRP Rebars in Bridge Decks with Corrosive Environments.
16. Evaluation of Steel Finger Joint Failure.
17. Over-height Load Impacts.
18. Utilization of MIRA for Assessing Bridge Deck Delamination.
19. Development of a Program to Select the Optimal Repair and Preservation Methods.
20. Scour Evaluation of Idaho Bridges.
21. Optimizing Bridge Hydraulic Evaluations.
22. Development of Eco-friendly Construction Materials for Idaho Bridges.
23. Development of Prestressing Precast Concrete Stiffleg Bridges and Culverts.

Projects one and four were later combined because both address deck issues and significantly overlap.

Top Six Ranked Projects

Project A - Evaluation of ITD's Bridge Deck Preservation Strategies

Research Project Description

Common practice for bridge deck preservation involves epoxy sealing shortly after construction or within a few years, with periodic reapplications of epoxy approximately every 10 years to extend the bridge deck life. Large or high-traffic bridges receive a more substantial initial overlay, followed by epoxy and periodic reapplications. The question is whether this strategy is optimal for preserving bridge decks in Idaho.

For new Deck Bulb-T girder bridges, ITD is routinely using Polyester Polymer Concrete overlays. These overlays are performing well but are expensive and require long waiting periods to be applied after closure pour placement between girders, contradicting the purpose of Accelerated Bridge Construction (ABC). The question is whether there are alternative overlays that may be an adequate solution.

Literature Review

This section presents a literature review on bridge deck overlay materials, construction, and rehabilitation strategies to extend the service life of concrete bridge decks. In particular, the research documents that have been published in the last 10 years are considered.

Bridge Deck Overlay Materials

FHWA 2016 – A FHWA report (2016) listed the top ten overlays and sealers used by State departments of transportation. Ranked by prevalence, these are: (1) asphalt overlay (with or without a membrane), (2) latex modified concrete (LMC) overlay, (3), epoxy polymer concrete overlay, (4) membranes (act as sealers), (5) Portland cement concrete overlay, (6) silica fume concrete overlay, (7) high molecular weight methacrylate (HMWM), sealer, prime coat, or overlay, (8) polyester polymer concrete (PPC) overlay, (9) silane sealers, and (10) low slump/dense concrete overlay. Figure 2.12 shows the types of overlays and sealers tried by State departments of transportation (Lane 2016), while Table 2.11 shows a comparison between epoxy polymer concrete and PPC. This document focuses on the use of overlays and sealers and the methods of evaluation by the State departments of transportation. For example, as shown in Figure 2.12, 33 State departments of transportation used epoxy polymer concrete overlays. From these, 16 rated the use of epoxy polymer concrete overlays as successful, and 2 States had stopped using it. Regarding the use of PPC, of the 16 States, 10 rated the use of PPC overlays as successful, and no States had stopped using PPC overlays.

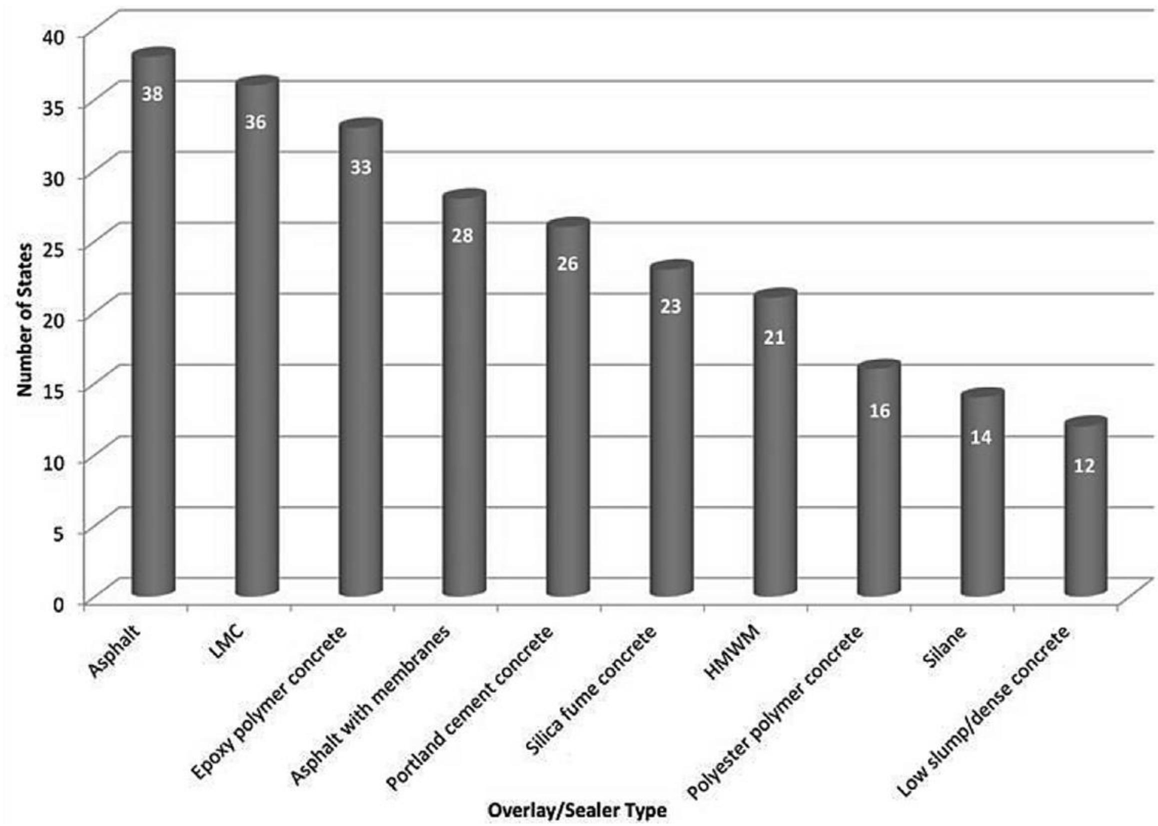


Figure 2.12 Types of overlays and sealers tried by State transportation departments (FHWA 2016).

Table 2.11 Typical properties of polymer binders and polymer concretes (FHWA 2016).

Property	Epoxy Polymer Concrete	Polyester Polymer Concrete
Viscosity of binder	200 to 2,000 cP	200 to 2,000 cP
Working life (gel time)	30 to 60 min	10 to 60 min
Curing time of concrete	3 h at 70 °F	1 to 5 h
Bond strength of concrete	1,500 psi	1,500 psi
Compressive strength of concrete	5,000 psi	4,000 psi
Flexural strength of concrete	2,000 psi	2,000 psi
Modulus of elasticity of concrete, compressive	0.9 to 1.5 x 10^5 psi	n/a
Modulus of elasticity of concrete, tensile	n/a	0.9 to 1.5 x 10^5 psi

n/a = Not available at this time.
cP = centipoise.

ITD 2023 – Sections 510, 551 and 553 of ITD's Standard Specifications for Highway Construction (SSHC) provide detailed descriptions, materials, and construction requirements for latex-modified concrete or silica concrete overlay, PPC overlay, and epoxy concrete overlays, respectively (Idaho Transportation Department 2023). For example, for PPC, ITD requires a HMWM resin primer, PPC resin binder, a prescribed combined aggregate gradation, and abrasive finish sand. Prior to application, the deck surface must be prepared by shot blasting. Similar requirements are prescribed for epoxy concrete overlay. PPC and epoxy overlay materials are acceptable alternate patching material for repairing minor potholes and delamination in the deck. Table 2.12 outlines ITD specification requirements for epoxy overlays.

Table 2.12 ITD's Standard Specifications for Epoxy Overlays

Property	Requirement	Test Method
Gel Time	≥ 15 to ≤ 45	ASTM C881, Paragraph 11.2 modified
Tensile Strength (neat)	≥ 2,000 psi to ≤ 5,000 psi at 7 days	ASTM D638
Tensile Elongation (neat)	≥ 40% to ≤ 80% at 7 calendar days	ASTM D638
Viscosity	> 7 to < 25 poises	ASTM D2393, Brookfield RVT Sindle No. 3 at 20 rpm
Minimum Compressive Strength at 3 hours	1,000 psi at 75 °F	ASTM C579 modified (with plastic inserts), mixed with aggregate
Minimum Compressive Strength at 24 hours	5,000 psi at 75 °F	ASTM C579 modified (with plastic inserts), mixed with aggregate
Minimum Adhesion Strength at 24 hours	250 psi at 75 °F	ACI 503R, Appendix A, VTM 92
Permeability to chloride ion at 28 days	100 coulombs maximum	AASHTO T 277

Iowa DOT 2016 – A research project was conducted at the Bridge Engineering Center at Iowa State University with the goal of investigating various ways to accelerate the construction of bridge deck overlays (Iowa Department of Transportation 2016). The final project report summarizes the current Iowa bridge overlay construction practices and recommends changes to save time and cost. It covers three main aspects of bridge overlay construction: overlay curing, construction management, and substrate concrete removal. Of the three main categories, the largest decrease of overlay construction time came from the overlay curing category. The project concluded that the following four fast-curing concrete overlay alternatives reduce curing time without a loss of strength: (1) CTS Rapid Set Low-P Cement Mixes, (2) 4x4 Concrete Mix, (3) PPC, and (4) Very-early-strength latex modified concrete (LMC-VE). Properties of these alternatives can be seen in Table 2.13, Table 2.14, Table 2.15, Table 2.16, and Table 2.17. The name 4×4 concrete refers to a form of concrete that achieves at least 400 psi of flexural strength within four hours of placement (BASF 2023).

Table 2.13 Properties of very-early-strength LMC (Iowa DOT 2016).

Property	Value	Curing Time
Traffic return time	3 hrs	3 hrs
Compressive strength (psi)	3000	3 hrs
	4000	6 hrs
	6500	5 days
chloride permeability (coulombs)	300-1400	28 days
	0-10	1 year
	0-60	9 years
Dry shrinkage (%)	0.02	170
Tensile adhesion bond strength (psi)	153-276	1-6 months
	176-301	9-10 years
Cost ($/yd^3)	140	

Table 2.14 Properties of 4x4 Concrete Mix (Iowa DOT 2016).

Property	Value	Curing Time
Traffic return time	4 hrs	4 hrs
Compressive strength (psi)	4130	4 hrs
	7740	24 hrs
	8250	28 days
Flexural strength (psi)	480	4 hrs
	855	24 hrs
	1250	28 days

Table 2.15 Properties of CTS Cement Rapid Set Low-P Mixes (Iowa DOT 2016).

Property	Value	Curing Time
Traffic return time	4 hrs	4 hrs
Compressive strength (psi)	4000-4500	3 hrs
	5000-6000	6 hrs
	8000-9000	28 days
Tensile bond strength (psi)	200-250	24 hrs
	600	7 days
	700	28 days
Slant shear bond strength (psi)	1200	24 hrs
	1900	7 days
	2200	24 days
Initial set	30 min	
Final set	40 min	

Table 2.16 Properties of HPC Concrete Mix (Iowa DOT 2016).

Property	Value	Curing Time
Traffic return time	72 hrs	72 hrs
Compressive strength (psi)	3000	3hrs or 1 day
	4000	12 hrs or 3 days
	7000	28 days
Flexural strength (psi)	300	3 hrs or 1 day
	600	12 hrs or 3 days
	1000	28 days
Permeability (coulombs)	500-2000	
Chloride penetration	< 0.07% Cl at 6 months	
Modulus of elasticity (psi)	5800000	
Abrasion resistance	0-1 mm depth of wear	
Absorption	2% to 5%	
Freeze-thaw resistance (durability factor for 300 to 1000 cycles	95 to 100	
Cost ($/yd^3)	119	

Table 2.17 Properties of Polyester Polymer Concrete (Iowa DOT 2016).

Property	Value	Curing Time
Traffic return time	2-4 hrs	2-4 hrs
Compressive strength (psi)	3982	24 hrs
	7000	7 days
	8030	28 days
Flexural strength (psi)	2200	28 days
Tensile strength (psi)	800	28 days
Chloride permeability (coulombs)	0-200	
Modulus of elasticity (psi)	1x10^6 - 2x10^6	
Abrasion (mm/year)	4 (8 to 10 times more than PCC)	
Cost (WSDOT-weighted ave $/sq ft)	10.73	

Virginia DOT 2017 – A research project conducted by the Virginia Transportation Research Council presented findings on the performance of bridge deck overlays in Virginia (Virginia Department of Transportation 2017). Some of these findings were based on prior research in bridge deck overlays, as shown in Table 2.18. This report addresses the concern of maintaining Virginia's transportation infrastructure, with a focus on bridge deck overlays as a rehabilitation method. Phase I of the study involves gathering information from the Virginia Department of Transportation's nine districts in relation to their experiences with various overlay types and factors influencing their overlay selections. Commonly used overlays include LMC, epoxy concrete, silica fume concrete, LMC-VE, and hot-mix asphalt concrete with a water-resistant membrane. Variability in overlay service life is observed, with construction workmanship and initial bridge deck conditions identified as critical factors.

Table 2.18 Service life of overlay types based on traffic volumes (Virginia DOT 2017).

Polymer Type	ADT < 5,000 (years)	5,000 < ADT < 25,000 (years)	25,000 < ADT < 50,000 (years)	ADT > 50,000 (years)
Multiple-Layer Epoxy	25	25	15	
Multiple-Layer Epoxy-Urethane	25	15	--	--
Methacrylate Slurry	18	7	5	3

Missouri DOT 2018 – Khayat and Valipour conducted a research project for the Missouri Department of Transportation on the use of a cost-effective ultra-high-performance concrete (UHPC) for bonded bridge deck overlays (Missouri Department of Transportation 2018). The report notes that UHPC prolongs the service life of bridge decks while offering shorter closure times. First, a UHPC was designed through the optimization of constituent materials. Then, the improved UHPC underwent various design and performance tests. Key findings include a design mixture methodology, considerations for binder systems, sand gradation optimization, and determination of volume ratios. Consideration was also given to effects of saturated lightweight sand and shrinkage-mitigating admixtures to the UHPC performance. Results show that UHPC overlay with 1 in. thickness is more cost-effective when compared with other types of overlay materials, such as latex-modified concrete and conventional bonded concrete overlays. It is worth noting that the unit cost of UHPC is much higher than comparative mixtures, as shown in Table 2.19. Costs represented in Table 2.19 strictly represent mixture costs and not costs incurred during transportation, mixing, or setting. There is a 1 in. thickness imposition on the thickness of the UHCP overlay to reduce the volume prior to mixture cost comparisons.

Table 2.19 Approximate Unit Costs of Comparative Bridge Deck Overlay Rehabilitation Mixtures ($/m3) (Missouri DOT 2018).

	MoDOT reference concrete mixture	Cost($)	Latex-modified Concrete (LMC)	Cost($)	UHPC	Cost($)
Type I/II Cement (kg/m^3)	280	40	390	56	-	-
Type III Cement (kg/m^3)	-	-	-	-	534	71
Class C Fly ash (kg/m^3)	95	5	-	-	-	-
Slag (kg/m^3)	-	-	-	-	491	52
River Sand (kg/m^3)	930	10	940	10	102	1
Masonry Sand (kg/m^3)	-	-	-	-	295	3
Coarse Agg. (kg/m^3)	930	10	740	8	-	-
Lightweight sand (kg/m^3)	-	-	-	-	406	37.6
CaO-based expansive agent (kg/m^3)	-	-	-	-	118	28.2
Latex (kg/m^3)	-	-	121	320	-	-
HRWR (l/kg^3)	1.25	6.5	-	-	46	177
Air-Entraining Agent (ml/kg^3)	28	0.5	-	-	-	-
Water (kg/m^3)	150	-	80	-	150	-
Steel fiber (kg/m^3)	-	-	-	-	147	648
Total cost ($/m^3)	-	$72	-	$394		$1,017.80

Caltrans 2019 – Cuelho and Stephens studied rehabilitation methods to extend the service life of bridge decks using polyester concrete overlays (California Department of Transportation 2019). This project was performed for the California Department of Transportation (Caltrans). In consultation with Caltrans, it was decided to test full size deck panels in the laboratory under a rolling wheel load shown in Figure 2.13. The laboratory bridge deck test panels were 7 feet wide by 8 feet 5½ inches long by 6½ inches thick. The test slabs were mounted in a test frame. As shown in Figure 2.13, the frame accommodated four slabs/panels loaded under traffic load sequentially by the automated loading device. Original polymer treatments were applied at approximately 25,000, 250,000 and 1,000,000 cycles of the applied load as shown in Figure 2.14. Kwik Bond Polymers PPC™–1121, a polymer-based overlay system, was used as the only rehabilitation technique in the second phase of the project as shown in Figure 2.15. Unfortunately, due to breakdowns of the loading device, funding issues, and both of the principal investigators leaving the university, the project was not completed, and the Analysis and Results section of the report is incomplete.

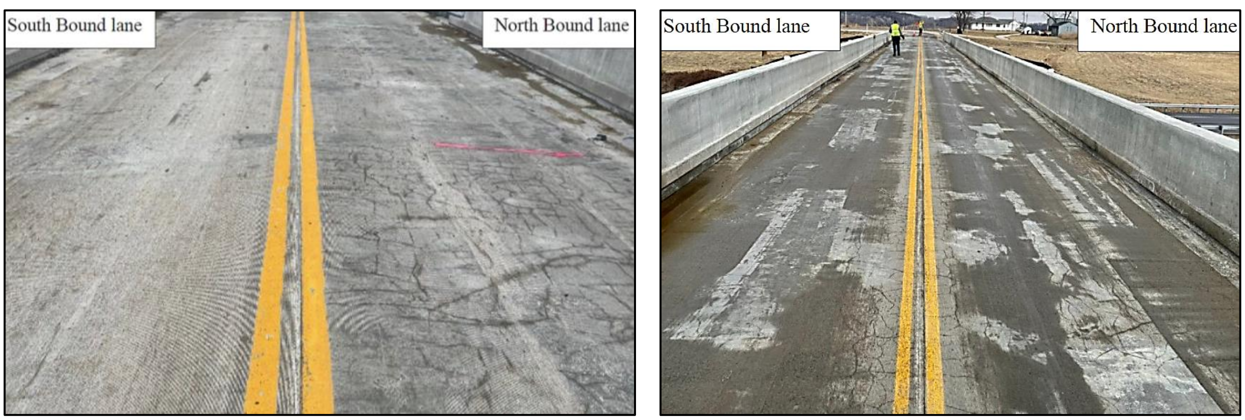
Figure 2.13 Automated bridge deck tester (Caltrans 2019).

(a) **(b)**

Figure 2.14 (a) Removal of spalled concrete, and (b) application of polymer treatment (Caltrans 2019).

Figure 2.15 Final surface of polymer overlay (Caltrans 2019).

Missouri DOT 2023 – Khayat, et al. performed the second phase of the use of non-proprietary UHPC as bridge deck overlay (Missouri Department of Transportation 2023). This phase focused on the constructability and performance of thin bonded UHPC overlay. Task 1 involved monitoring crack density, overlay-substrate bond strength, and flexural behavior for 16 composite overlay slabs. The slabs were 39 × 79 in. with a depth of 6 in. and were made with conventional concrete with 28-d compressive strength of 5,800 psi and reinforced with two mats of #4 longitudinal bars. The overlay materials included a conventional concrete (CC), a LMC, and five non-proprietary UHPC. After approximately 33 months of outdoor exposure, no surface cracking was observed for the UHPC overlay. Task 2 involved fine-tuning the UHPC mixes including adding shrinkage-reducing admixture. Task 3 involved developing specifications for non-proprietary UHPC for bridge overlay construction. Task 4 was the implementation using two of the better performing non-proprietary UHPC mixes for the rehabilitation of two Missouri DOT bridge decks. The bridge overlay placement took place between October 20 and November 6, 2022. As shown in Figure 2.16, the results were mixed. The field inspection three months after overlay placement showed that on South Bound Lane Route Z Bridge there were no cracks, but on the North Bound Lane there were many cracks. Overlay cracks were also seen on both lanes of the Route M Bridge. On the Route Z Bridge the cracking was attributed to quality control issues, while on the Route M Bridge, the cracking was attributed to a sharp drop in temperature. A lack of continuous moist curing was also noted as a possible factor for overlay cracking.

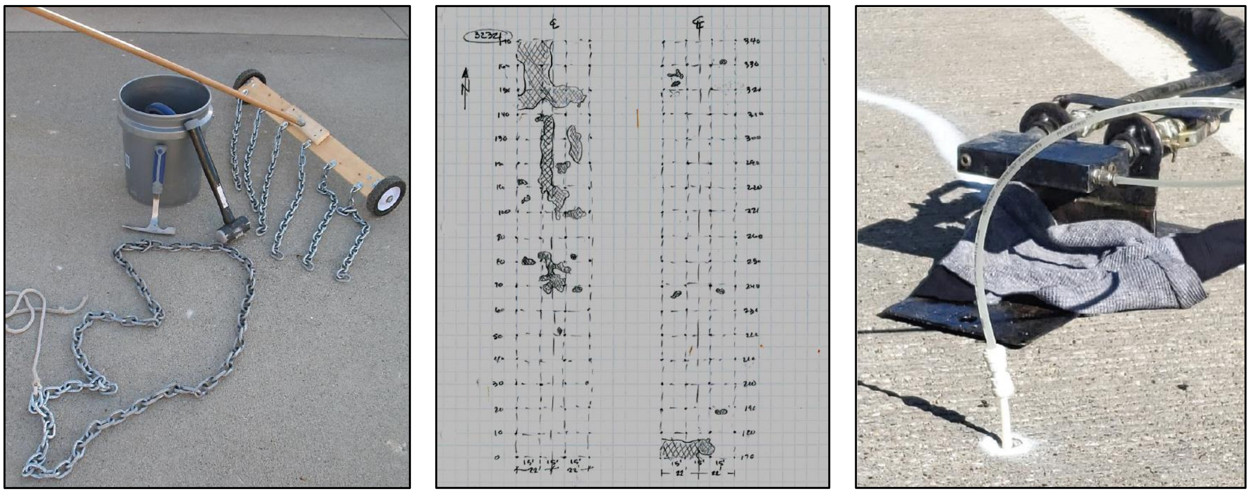


(a) **(b)**

Figure 2.16 Overlay cracking in (a) Route Z Bridge 96 days after placement, (b) Route M Bridge 81 days after placement (Missouri DOT 2023).

Bridge Deck Epoxy Injection

Iowa DOT 2019 – In a report for the Iowa Department of Transportation (2019), Wipf, et al. evaluated Iowa's bridge deck epoxy injection process. The research objectives were to (1) determine the effectiveness of epoxy-injected delaminated bridge decks, (2) review the epoxy injection in the U.S., and (3) develop procedures and specifications for epoxy injection. As a part of the study, field evaluations were conducted on 24 bridges in Iowa including: performance evaluations, visual inspections, and "sounding" of the concrete overlay. Sounding was done by dragging chains and hammer tapping identifying the delaminated portions of the overlay by tonal fluctuations. Figure 2.17 shows the equipment used in the sounding inspection, a typical delamination map, and the epoxy injection process. The results of this project show that epoxy injection can extend the service life of a bridge deck by at least four years. In addition, the report noted that epoxy deck injections were not effective once a certain threshold of deterioration was present.



(a) **(b)** **(c)**

Figure 2.17 (a) Delamination detection tools, (b) delamination map, and (c) epoxy injection (Iowa DOT 2019).

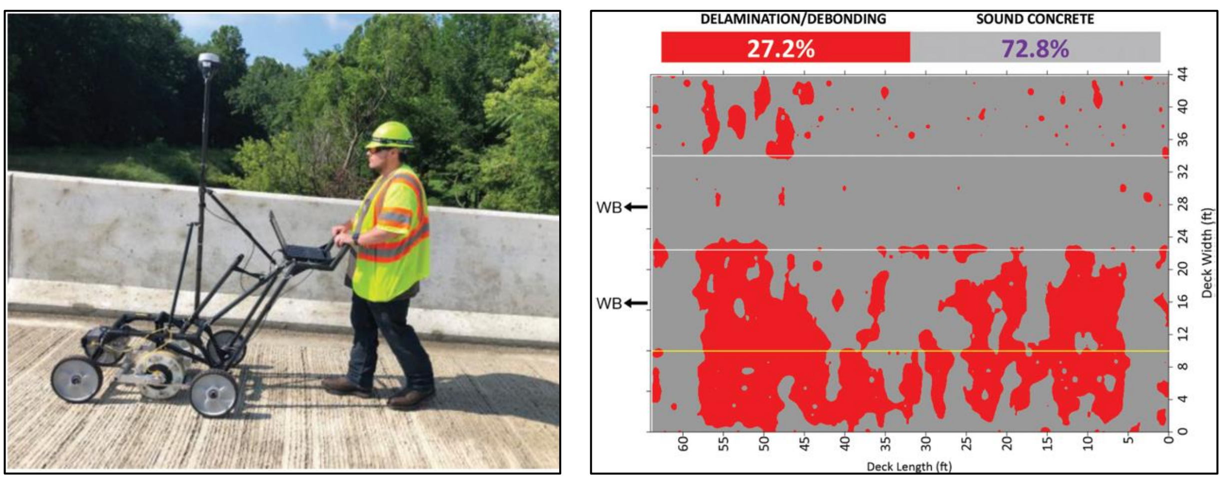
***Indiana DOT 2023* –** A recent joint report by Indiana Department of Transportation and Purdue University, Baah (2023) investigated the viability of epoxy injections to repair concrete overlays that are found to be de-bonded from the deck concrete. An impact echo sonic surface scanner was created to provide impact echo damage maps, shown in Figure 2.18, that identify this de-bonding. The report suggests candidate selection criteria of bridge decks with

- De-bonded rigid concrete overlay,
- Tight surface cracks,
- Light to no cracking of soffit,
- Very little to no spalls,
- Delamination not exceeding 30% of deck area,
- Deck rating greater than or equal to 5,
- Wearing surface condition rating greater than or equal to 4.

The findings of this research suggest guidelines for a step-by-step injection process and recommends the following maintenance life cycle for a typical bridge:

- Year 3 and 6: Maintenance Silane Spray and Crack Filling,
- Year 10: Thin Deck Overlay #1,
- Year 20-25: Thin Deck Overlay #2,
- Year 30-40: LMC Overlay #1,
- Year 40-55: Epoxy Injection,
- Year 50-60: Possible LMC Overlay #2,
- Year 60-70: Possible Epoxy Injection,
- Year 50-75: Deck Replacement.

The report concludes that epoxy injection is a proactive and cost-effective alternative to traditional deck patching, offering advantages such as reduced manpower and lower costs. This method, added to Indiana Department of Transportation's standards, involves filling voids created by debonding between concrete overlay and deck concrete with epoxy, mitigating freeze/thaw cycling and spalling. By protecting against moisture and providing support, epoxy injection extends bridge deck lifespan, enhancing overall infrastructure performance. Recommendations include a district-wise minimum of five epoxy injections annually, incorporation into the Maintenance Work Plan, and ongoing monitoring for effective maintenance and performance assessment.



(a) (b)

Figure 2.18 (a) Impact Echo Sonic Surface Scanner, (b) Impact Echo damage map (Indiana DOT 2023).

Additional Research Projects

Several projects are found in the Transportation Research Board (TRB) database that consist of a combination of highly relevant ongoing projects and projects that final reports could not be located. In order of TAC member rankings, these projects are:

1. Evaluation of Multi-Layer Polymer Concrete Overlays
2. Evaluation of Thin Polymer Overlays for Bridge Decks
3. Field Implementation and Monitoring of an Ultra-High Performance Concrete Bridge Deck Overlay
4. Performance Evaluation of Polyester Polymer Concrete Overlays Continuation Proposal Phase II TR-772
5. Alternative High Early Strength Concrete (HESC) Structural Overlays
6. Optimization of Advanced Cementitious Material for Bridge Deck Overlays and Upgrade, Including Shotcrete
7. Fiber Reinforced Concrete Overlays for Bridge Structures
8. UHPC Thin Bonded Overlay on Deteriorated Bridge Decks
9. Rehabilitation of Deteriorated Bridge Decks with Ultra-High Performance Concrete Overlays
10. Optimized performance of UHPC bridge joints and overlays
11. Sustainable nHPC Mixtures for Durable Overlay of Concrete Bridge Decks in Cold Regions: Proof of Concept

Project B - Implementation of Internal Concrete Curing (ICC) to Enhance Concrete Performance

Research Project Description

Premature cracking of bridge decks has been a problem for several DOTs in the last decade, and most of the DOTs engineers have used various concrete mixtures, types (high performance concrete), and admixtures to prevent it and to control such cracking. Once concrete cracking starts in concrete pavement and bridge elements, the cracks get wider under service loads and due to harsh environment. Cracking reduces the service life of roads and concrete bridge members, and consequently increases maintenance and replacement cost. Most of the DOTs currently use high performance concrete (HPC) in bridge decks for high compressive strength and durability, however the low water-to-cement ratio might compromise its service life (FHWA 2003). ITD has employed mitigating approaches such as crack sealing and thin polymer overlays to address early-age deck cracking. However, these strategies are costly and have impacts on traffic operations due to the need for repeated applications through the life of the pavement and structures. Internal curing of concrete structures has been used in various states such as Illinois and Wisconsin as a strategy to control concrete cracking during service life. The main goal of this project is to use presoaked aggregates (PA) in concrete mixtures as an internal curing (IC) method that reduces drying shrinkage over time. The benefit of presoaked aggregates is significantly reduced drying shrinkage especially if used with shrinkage reducing admixtures (SRA), Ardeshirilajimi et al. (2016). The second goal of this study is to investigate the effect of using presoaked aggregates on the Alkali Silica Reaction (ASR) of ITD concrete mixtures.

Preliminary Literature Review

Ponding, fogging, spraying, and the use of wet burlap are examples of traditional concrete curing techniques. However, capillary porosity is usually separated during the initial few days of hydration in concretes with low water-to-cement (w/c) ratios, including high-performance concrete (Aitcin 2003). As a result, only a few millimeters of external water may enter the concrete, while the interior of the concrete severely dehydrates due to self-desiccation (Bentz 2002, 2007). On the other hand, water can be distributed more evenly across the concrete's cross section through internal curing (Castro et al. 2011). Therefore, the objective of internal curing is to supply enough water in the right locations to enhance cementitious component hydration and reduce autogenous stresses and strains. Consequently, internal curing may improve strength, decrease permeability and porosity, (Bentz and Weiss 2011).

In an effort to solve the issue of shrinkage-related early-age cracking in concrete pavements and bridge decks, a few state Departments of Transportation have recently looked into the idea of IC. An additional moisture supply from within is provided by internal curing, which can counteract the effects of delayed strength development, suspended hydration, autogenous shrinkage, and early age cracking. Internal curing has been shown to lessen early-age shrinkage and the corresponding plastic shrinkage cracking (Ibrahim et al. 2016). The internal curing process in concrete pavements and bridges has been shown by several state DOTs, including the DOTs of Louisiana, Indiana, and Illinois, to reduce crack intensities and triple the service life of the sections under study (Barrett et al. 2015, and Rupnow et al. 2016).

Due to HPC's compact structure and extremely low permeability, shrinkage and cracking issues cannot be addressed by traditional complete water curing, despite the material's growing use in Idaho. ITD wants to assess performance and get clear documentation of internal curing processes based on the effective methods used by other state DOTs. However, no study has been conducted in Idaho on the design, construction, and performance assessment of HPC enhanced by IC. Lack of mix design guidelines, lack of construction expertise, absence of standard performance evaluation processes, and lack of internal curing agent selection criteria were the reasons behind the implementation of IC method. It is difficult to guarantee the performance of transportation structures constructed with internally cured concrete without this thorough study. It is crucial that ITD ascertains what modifications to its specifications are required to allow for internal curing. To guarantee the best possible performance of internal curing in ITD concrete building projects, standard guidelines must be created due to the diverse combinations of new materials, procedures, and construction techniques. With such guidance, ITD will be able to fulfill its strategy of matching investment with service while optimizing performance at the lowest possible life cycle cost. Idaho expects to remove obstacles to the effective control of early-age cracking in bridge deck concrete as the recommendation is developed and put into action.

The following entries are summarized from their respective literature:

Oregon DOT (Ideker et al. 2013) - The study aimed to evaluate the long-term drying shrinkage performance of two methods—pre-soaked fine lightweight aggregates (FLWA) and shrinkage-reducing admixtures (SRA)—for new bridge deck construction. The goal was to shorten the current external curing duration of 14 days as specified by the Oregon Department of Transportation. Additionally, the study assessed the durability of these methods, including freeze-thaw testing, permeability testing, and restrained drying shrinkage testing, to ensure they performed similarly or better than the current mixture design.

The study found that both pre-soaked FLWA and SRA effectively reduced long-term drying shrinkage. However, the combination of the two methods was the most effective for reducing long-term drying shrinkage across all curing durations (1, 7, and 14 days). For durability testing, SRA performed the best in freeze-thaw testing, chloride permeability, and restrained shrinkage compared to the control group.

Louisiana 2016 (Rupnow et al. 2016) - Proper curing is essential for durable and sustainable concrete structures. It is the final and most critical step in the process, following concrete design, delivery, pouring, and consolidation. Insufficient curing can lead to concrete cracking, resulting in a non-durable and non-sustainable structure.

The centrifuge test method for determining aggregate free moisture is superior to the paper towel test method in terms of speed and repeatability of results. Laboratory tests indicated that using lightweight fine aggregate for internal curing does not negatively affect fresh concrete properties. Compressive strength and modulus of elasticity were found to be the same or slightly higher with internal curing, while flexural strength was slightly reduced compared to control. Internally cured concrete (ICC) showed increased surface resistivity values, indicating improved hydration.

Field trials demonstrated that ICC performs well. The West Congress project showed reduced cracking after one year compared to control sections, and the Ada project had significantly less cracking nine months after ICC placement. The section placed without curing compound for a 150 pound per cubic yard ICC mixture has yet to crack, even under worst-case conditions. Reduced cracking leads to longer service life and a more durable structure.

Contractors also reported that ICC is easy to work with and finish, stating that it behaves like normal concrete. Based on laboratory and field results, a standard lightweight fine aggregate replacement rate between 225 and 275 pound per cubic yard is recommended for implementation.

Indiana 2013 (Barrett et al. 2013) - The Indiana Department of Transportation constructed four bridge decks using internally cured high performance concrete (IC HPC) in the summer of 2013. This construction applied research findings suggesting internal curing as a method to decrease the risk of shrinkage cracking and enhance durability, as outlined in the FHWA/IN/JTRP-2010/10 report.

The study aimed to document the construction of the four IC HPC bridge decks in Indiana in 2013 and assess their properties and performance. The report includes documentation of IC HPC concrete production and construction for the four bridge decks. Samples of IC HPC were compared with a reference HPC without internal curing and analyzed in the laboratory for mechanical properties, chloride resistance, shrinkage, and cracking potential.

Based on experimental results and mixture proportions, the diffusion-based service life of the bridge decks was estimated. The study found that IC HPC mixtures produced in this research could more than triple the typical bridge deck service life in Indiana, while reducing early age autogenous shrinkage by over 80% compared to non-internally cured concretes.

Illinois 2016 (Ardeshirilajimi et al. 2016) - This report explores the use of pre-soaked lightweight aggregates (LWA) in concrete as an internal curing agent to minimize cracking due to drying shrinkage. While LWA is effective in reducing autogenous shrinkage, its impact on drying shrinkage is limited and may even increase it in some cases. The report also examines the combined effects of LWA with expansive cement (Type K) and LWA with shrinkage-reducing admixtures (SRAs) on drying shrinkage. The findings indicate that adding Type K cement or SRA to mixtures containing LWA can significantly reduce drying shrinkage and enhance volumetric stability.

Nebraska 2020 - This research project aimed to develop internally cured bridge deck concrete using a local mix design in Nebraska. Due to high cement content and a low water-to-cement ratio, bridge deck concrete is susceptible to premature cracking. Internal curing can significantly mitigate the risk of premature cracking and concrete deterioration.

The study evaluated four different lightweight fine aggregates (LWFAs) as internal curing agents, examining their effects on the fresh, mechanical, durability, and shrinkage properties of concrete. To identify the most effective LWFA dosage for reducing shrinkage, different replacement rates of sand and gravel with LWFA were tested to account for moisture loss during construction and drying. Aggregate blends were optimized to account for changes in aggregate gradations due to the introduction of LWFAs.

The research demonstrated the feasibility of developing a local internally cured concrete mix that is both technically and economically viable. Although the replacement of fine aggregates with LWFAs resulted in lower 28-day modulus of elasticity and modulus of rupture, the overall mechanical properties still met bridge deck criteria.

Internally cured mixes showed resilience with reduced curing age requirements, as the saturated LWFAs provided internal curing water. Additionally, internally cured mixes exhibited similar chloride penetrability to the control mix, falling into either very low or low chloride ion penetrability categories based on lab studies.

Wisconsin DOT (Pacheco et al. 2021) - This research project evaluated internally cured concrete mixtures for bridge decks and pavements, aiming to minimize volumetric changes such as cracking and warping. The study included a literature review of internal curing technology and experiences in the US, a survey of existing internally cured bridge decks in Illinois, and assessments of different materials as internal curing agents for concrete bridge decks and pavement.

During material evaluation, fourteen different materials were assessed for absorption and desorption properties. These materials fell into three groups: lightweight aggregate fines (LWA), superabsorbent polymers (SAP), and fibers. Based on their performance, one LWA and one SAP were selected for implementation in concrete mixtures.

The study evaluated the performance of internally cured concrete (ICC) through tests on fresh and hardened concrete properties for one control and two ICC mixtures (one with LWA and one with SAP) at two different water-to-cementitious materials ratios (w/cm). Results indicated improvements in volumetric stability and durability of ICC when the w/cm ratio was 0.36, while minimal improvements were observed at a w/cm ratio of 0.45.

Service life modeling for a bridge deck scenario and a life cycle cost analysis (LCCA) for a pavement project were conducted, showing that ICC can extend the service life of bridge decks and reduce the LCCA of a pavement project compared to a control scenario.

The research concluded with recommendations for implementing ICC into Wisconsin Department of Transportation specifications.

Project C - Development of More Reliable Camber Prediction for Prestressed Deck Bulb-T girders

Research Project Description

It has been noted that the current camber prediction system for prestressed concrete Bulb-T girders underestimates or overestimates the long-term camber of some of Bulb-T girders. The timing of bridge construction has a significant impact on long-term camber prediction. Moreover, even though they were all the same type and length, it has been discovered that Bulb-T girders cast on the same bed might have different cambers. Construction costs have gone up because of this inconsistency and the inability to estimate the long-term camber accurately, raising questions about quality control. Bulb-T girders have a highly complex camber due to their sensitivity to various fabrication procedures, including mix design, bed configuration, curing process and handling, tolerances on prestressing pressures and moisture control, storage environment, and support location during storage. The type of aggregates, cement, and admixtures used in the concrete also affects concrete creep and shrinkage, which significantly impacts long-term camber. This study aims to provide improved camber control for standard Bulb-T girders that are frequently used in Idaho by systematically identifying the most important parameters, practices, and predictive analytical models.

No reinforced concrete is placed on top of Deck Bulb-T girders in Idaho. The currently used ITD camber calcs formulas usually underestimate the actual cambers and very seldom overestimate them. No significant flexural cracking of top flanges has been observed due to underestimated camber predictions. ITD typically uses uniform 3/4" PPC overlays on top of Deck Bulb-T girders after their erection. Out of spec cambers result in the need for additional, sometimes substantial and nonuniform increases of overlay thickness, adding unintended weight, cost, and difficulty in maintaining smooth and as designed bridge deck profile.

Preliminary Literature Review

Camber is the net upward deflection (Figure 2.19a) that results from the self-weight of a precast pretensioned concrete beam (PPCB), which usually happens from the moment caused by the prestressed strands eccentricity. The upward net deflection that occurs right after the transfer of prestress is known as the instantaneous camber, and it is frequently used to predict the long-term camber. Therefore, the instantaneous camber influences the accuracy of the long-term camber in addition to the camber at erection and subsequent stages of the girder. Usually designers use Martin's multipliers (1977) and an elastic analysis to determine the camber at release and at the erection time of bridge girders. However, there are various factors that affect the at-erection camber, such as support placements, material qualities, concrete creep, age of girders, and vertical temperature gradients throughout the section depth, that are unknown at the time of design and not currently considered, and to name a few.

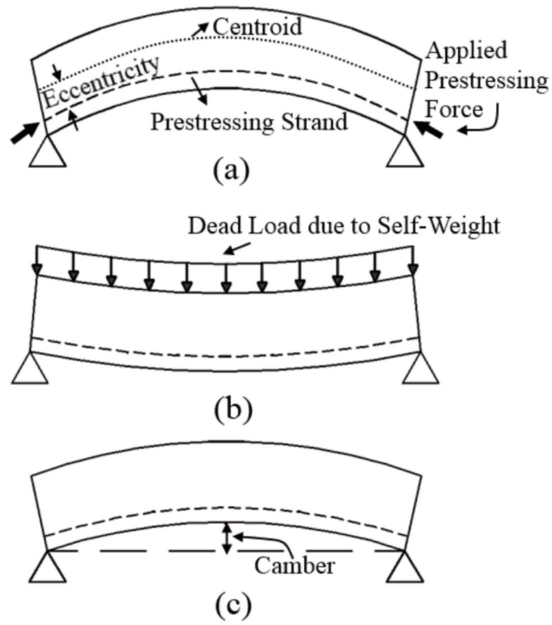


Figure 2.19 (a) Deflection due to prestressing force, (b) deflection due to self-weight, (c) camber, Honarvar et al. 2015.

The general equation for camber is based on:

$\Delta_{Camber} = |\Delta_{Prestress(Upward\ Deflection)}| - |\Delta_{Self\text{-}Weight(Downward\ Deflection)}|$

Usually, the long-term camber is determined by deducting the long-term prestressing deflection from the long-term self-weight deflection.

The following sections present a literature review on the development of more reliable camber prediction for prestressed concrete girders.

Idaho Study (Brown 1998) – The existing models for determining the time-dependent camber of prestressed concrete girders were examined by Brown (1998). It was suggested to estimate the camber at the time of erection using a straightforward formula and a time-dependent model for future camber prediction. The data supplied by Idaho girder manufacturers was compared to the camber predictions made by both methods. Lastly, the author offered pertinent methods for forecasting Idaho's future camber prediction.

Washington State DOT Rosa et al. 2007) – Rosa et al. (2007) developed a computer code to predict camber as a time function in an effort to increase the accuracy of camber prediction. The long-term camber computations were compared with the measured values of 91 girders. The camber predicted by the computer code was compared with the measured camber from 146 girders. To reduce the error in the camber predictions, the program was calibrated. When raising the girder and measuring the distance to the casting bed at both ends and the middle, the researchers' self-leveling laser level measurements of camber were compared to the precast yard's measurements produced using a tape. There was a 0.25-inch difference in the measurement techniques.

The study suggested using the AASHTO equations to calculate concrete's modulus of elasticity and creep coefficient, multiplied by adjustment factors of 1.4 for creep coefficient and 1.15 for the modulus of elasticity. Local material testing should be conducted to calculate these factors for other environmental conditions. The creep component of camber prediction also needed to be calculated with the prestress losses considered. The report noted that the camber calculations must account for the beam overhang impact caused by temporary supports. The modified WSDOT method reduced the average error to 0.14 in. when using the design concrete strength and 0.03 in. when using the measured concrete strength.

Oklahoma Study (Jayaseelan and Russell 2007) – The purpose of this study was to review the pertinent literature regarding prestress loss prediction. The study also investigated the differences in the qualities of the concrete material. The ODOT was advised to calculate prestress losses, camber, and deflection with greater accuracy based on the following suggestions:

The long-term prestress losses and camber in prestressed concrete girders can be reduced by approximately 69% by adding top prestressing strands.

- The long-term camber can be reduced by approximately 17.4% by adding mild steel.
- The losses and camber in prestressed concrete bridge girders can be calculated using the AASHTO Time-Step method.

Numerous prior research works have emphasized the challenges associated with both short- and long-term camber prediction. Aside from equation improvements, accuracy was still within ±15%. The majority of previous research showed that camber was overpredicted, however some investigations found that camber was underpredicted in shorter girders. Errors in camber calculations were primarily caused by the following factors:

- Concrete modulus (several studies supported the AASHTO 2010 equation for modulus with k1 factors from 0.85 to 1.2),
- Concrete compressive strength (on the order of 22% higher at release),
- Temperature (fluctuations in daily temperature can cause a 0.75-inch shift in camber, and variations in ambient and curing temperatures can reduce the prestress force upon release),
- The AASHTO creep and shrinkage models are the ones that most studies recommend using, but some (Honarvar et al. 2015, Stallings et al. 2003) used modification factors.
- Other factors to consider include storage locations (overhang length in storage affects the girder camber, and most studies recommend including the effect),

- Initial prestress variability, and girder self-weight variability.

North Carolina DOT Study (Rizkalla et al. 2011) – To enhance camber predictions, Rizkalla et al. (2011) carefully examined variables associated with girders' production. These included the effect of thermal gradients, debonding length, variation of prestress force with temperature (for 60°F temperature change during curing, prestress force can reduce by 7%), variation of concrete properties at release (on average 25% higher than design), concrete compressive strength at 28 days (on average 45% higher than design), and concrete elastic modulus (15% less than AASHTO predicted) are among the factors taken into consideration.

The study proposed a detailed method and an approximate method for camber prediction. Correction factors for both methods used included: 1.25 for the design release compressive strength of concrete, 1.45 for the design 28-days compressive strength of concrete, and 0.85 for the concrete modulus of elasticity k1 factor in the AASHTO LRFD model. The proposed method uses AASHTO (2012) for calculating the prestress losses, concrete creep, and concrete shrinkage, which is the same as MoDOT specifications. The author recommended recognizing the temperature gradient effect on the camber measurement and found that the transfer length of the prestressed girders affected the camber of the PPCB. However, the method ignores the effect of the overhang on the camber prediction. The original NCDOT method over-estimated the camber of girders by an average of 52%, while the proposed approximate method reduced this to 16% and the detailed method to 6%.

Iowa DOT 2015 – The Iowa Department of Transportation (Iowa DOT) has experienced differences in the measured and calculated camber of precast pretensioned concrete beams (PPCBs) that have caused problems in the field during bridge construction. Those differences have led to delays and extra cost. To reduce such issues in the field, this study was conducted to methodically determine the possible causes of variations between the designed and measured camber from the prestress release time to the time of girders erection. The goal from this study is to increase the accuracy of camber calculations.

Engineering characteristics, such as creep and shrinkage, of three standard concrete mix designs and four high-performance concrete mix designs were characterized to successfully complete the project's objectives. More than 100 prestressed concrete girders have been used to assess the influence of various factors in determining the corresponding instantaneous camber and the variables influencing it. The long-term camber was predicted for 66 prestressed concrete girders using a combination of finite element studies and a time-step approach, taking into account changes in the location and prestress forces, creep and shrinkage of the concrete, and the effects of heat.

To more precisely calculate the at-erection camber based on the predicted instantaneous camber, several types of multipliers were recommended for design, including multiplier power functions, a series of average multipliers, and a single multiplier. These multipliers were all created both with and without the overhang's effects. Nevertheless, the multiplier approaches' accuracy was improved by removing the overhangs' contribution to the long-term camber. Furthermore, to compensate for the increased deflection brought about by the thermal effects, a temperature multiplier, λ_T, was included. Overall, compared to the existing Iowa DOT approach, the long-term camber estimation was greatly improved using the recommended multipliers, temperature multiplier, and modified data for the overhangs, with the following conclusions:

- The suggested measuring technique found and removed the sources of errors brought about by the existing instantaneous camber measurement techniques.
- The best agreement between the measured and planned instantaneous camber was found using the modulus of elasticity determined using the AASHTO LRFD (2010) and based on the specific unit weight and release strengths corresponding to the individual PPCBs.
- When multipliers were included, the accuracy of the long-term camber prediction was also increased by decreasing the errors in the instantaneous camber forecast.
- Using the proposed average observed creep coefficient and shrinkage strain, the errors in the long-term camber predictions related to the time-dependent material properties were reduced.
- The long-term camber predicted by Naaman's (Naaman et al. 2004) method correlated better with the measured long-term camber than Tadros' (Tadros et al. (2015), method and the incremental method for the prediction of the long-term camber using a simpler analysis.
- The accuracy of the long-term camber predictions was much increased by using the complex analytical models that were created with creep and shrinkage considered, as well as changes in prestress and support locations and thermal effects.
- When the multipliers were modified to take into consideration the overhang length and the thermal effects, the generated multipliers outperformed the current Iowa DOT technique in terms of long-term camber predictions.
- Comparing the measurements from the four HPC and three NC mixes over a one-year period with the AASHTO LRFD (2010) creep and shrinkage models, it was shown that the models provided the best estimations. The ACI 209R-92 model, the ACI 209R model modified by Huo et al. (2001), the CEB-FIP 90 model, and the B3 model by Bazant (2000) were among the other models examined.
- Despite being determined to be superior to the other four models, the AASHTO LRFD (2010) model underpredicted the creep coefficient and shrinkage stresses by an average of 32% and 44%, respectively, and there were still significant errors between the measured and projected values.

Tadros et al. (2015) – The concrete modulus of elasticity (22% error), curing vs. ambient temperatures reducing prestressing force, location of lifting inserts and storage support points location, and errors in the estimation of prestress force and girder self-weight are among the causes of initial camber variability, according to a study by Tadros (2015). The author recommended measuring the camber in the morning for a neutral thermal gradient and letting the girder cool for 72 hours before measuring the camber to eliminate the effect of the strand de-tensioning owing to curing temperatures. Nevertheless, the accuracy of camber prediction might only be within ±25%. Tolerance levels were advised to be ±½ in. for an anticipated camber of less than 1 in. and ±50% for predicted cambers of more than 1 in.

Nguyen et al. (2015) – Before casting bridge deck, Nguyen et al. (2015) investigated the effects of temperature change on the camber prediction. The authors of the study described an experimental project that includes temperature and prestress girder camber monitoring. According to the experimental work, the top flange of two girders (lengths of 172 feet and 164 feet) may attain a temperature of 100°F, while the bottom flange remains at 65°F. One day's temperature fluctuation resulted in 0.6 inches of camber change and 0.5 inches of girder length change. Theoretical camber resulting from temperature variation was validated using experimental data. A novel and feasible technique has been developed that enables the designer to predict camber in a bridge girder resulting from temperature fluctuations throughout the day.

Arkansas DOT (Mohammedi and Hale 2018) – The goal the study conducted in Arkansas was to increase the accuracy of camber predictions for prestressed concrete girders. The measured actual camber values were less than the design values because the actual concrete compressive strength was higher than the design values by 26%-80%. In addition, the concrete measured elastic modulus was higher than the design values by 20%-50%. Based on the aggregate source and compressive strength of concrete, the researchers suggested a k1 correction factor of 1.0 to 1.2 in the AASHTO (2014) calculation for concrete modulus. In addition, the long-term camber multiplier was also changed from 2.45 to 1.4. The difference between the measured and computed camber is reduced by these adjustments.

Mississippi DOT (Tomley 2019) – Since Mississippi DOT encountered over-prediction of camber of prestressed girders on multiple projects, the goal of this research was to enhance camber prediction. To accomplish this, the author looked at the camber prediction procedures used by a number of states and assessed past material property data. Updated multipliers with some material property data enhancements were presented for long-term camber prediction.

Missouri DOT (Orton et al. 2021) – The goal of this study was to create precise prestressed girder camber calculations and evaluate them using existing data. The project team studied current girder camber research initiatives in other states and performed a thorough analysis of the literature (Table 2.20). The project gathered the available information on 189 bridge girders in Missouri and used field data. The camber prediction equations and parameters were evaluated and compared to the field data. According to the study, the existing prediction approach, on average, underestimated the initial camber observed in the field by around 25%.

Investigation did show that sag in the measurement string line may have contributed to inaccuracy in the field data. In addition, the camber was impacted by the overhang, or the length of the girder past the support points. It was shown that temperature variations could also cause camber inaccuracy. The effect of the girder overhang and a continuous time-dependent camber forecast were added to the existing camber calculations. Guidelines for measuring camber were also developed. With the changes made to the camber prediction, the average underprediction of camber was lowered to less than 4%, and the average inaccuracy was reduced from 35% to 20%. As a result, most of the time the forecasts came within ±25% of the measured camber. For ease of calculation, the suggested approach was included in a computer spreadsheet.

The main changes in the camber calculation equations compared to the current MoDOT method are:

- Incremental time-step approach was developed, where camber could be predicted at any point in the life of the bridge girder.
- The effect of overhang length on camber was included.
- The effects of prestress loss due to elevated concrete temperatures during curing and daily temperature effects on camber were included.

Table 2.21 shows the factors affecting the initial camber calculations.

Table 2.20 Camber prediction calculation methods for various states (Orton et al. 2021).

State (year)	Method	Conclusion
Alabama (Stallings et al. 2003)	Monitored five AASHTO BT-54 girders for Alabama's HPC Showcase Bridge.	Existing analytical methods can lead to accurate expectations of HPC girder camber and prestress losses if the properties of the material used in the calculations are measured in girder construction.
Arkansas (Mohammedi and Hale 2018)	9 PPCB instruments and materials tested.	Underestimation of concrete elastic modulus and prestress losses. Suggest a modification to the long -term multiplier.
Idaho (Brown 1998)	Theoretical analysis of time-dependent camber.	Developed a time-dependent model for camber prediction.
Iowa (Honarvar et al. 2015)	Measured material properties, considered data for instant camber of 100 PPCBs, monitored long-term camber 66 PPCBs.	Recommended best practices for camber measurement and proposed new long-term multipliers.
Minnesota (O'Neill and French 2012)	Examined camber records of 1,000 PPCBs, measured material properties.	Found higher than design concrete strengths, and lower strand stress at release due to thermal effects and relaxation. Developed multipliers to predict long-term camber.

State (year)	Method	Conclusion
Mississippi (Tomley 2019)	Examined camber prediction practices of several states, evaluated historical material property data.	Suggested improvements to material property data and revised multipliers for camber prediction.
Missouri (Yang and Meyers 2005, Gopalaratnam and Eatherton 2001)	Evaluated prestress loss estimates in an HPC bridge. Monitored an extensively instrumented HPC bridge.	Compared prestress loss estimates and recommended procedure, evaluated prestress losses, creep and shrinkage, and temperature effects.
North Carolina (Rizkalla et al. 2011)	Evaluated material property data and other factors for camber prediction with field instruments and site visits.	Concrete strength, form deformations, debonding length, and temperature gradient affected camber prediction. Developed detailed and approximate method to predict camber.
Oklahoma Jayaseela and BRUCE 2007)	Analytical investigation on parameters affecting long-term deflections and camber.	AASHTO time-step methods, NCHRP 496, and PCI Design Handbook method produced comparable results.
Texas (Byle et al. 1997, Bayrak et al. 2012)	Measured camber and prestress loss and compared predictions. Evaluated prestress loss prediction.	Analytical time-step program produced accurate results, proposed multipliers for hand calculations, developed new prestress loss prediction formulas.
Washington (Rosa et al. 2007)	Time-dependent computer analysis verified with measured camber.	Response in sensitive to prestress loss, elastic modulus, and creep coefficient. Applied adjustment factors for elastic modulus and creep coefficient.

Table 2.21 Factors affecting initial camber calculation (Orton et al. 2021).

Factor	Details	% Effect on Camber
Concrete compressive strength	The compressive strength varies with time, so the time of camber calculation is important. Also, the aggregate strength, the ratio between the aggregate and cement paste, and the type of cement affect the camber.	Increasing the compressive strength by 10% leads to a decrease in the initial camber calculations by about 4%.
Concrete modulus	The concrete stiffness (modulus) is directly related to the concrete strength and varies with time. It is important that prestress loss and early age detection computations include explicit modeling of the elastic modulus of concrete.	Increasing the concrete stiffness by 10% leads to a decrease in the initial camber calculation by about 8%.

Factor	Details	% Effect on Camber
Prestress force	Prestress force is affected by many factors like the jacking force, strand temperature variation, and prestress losses.	Decreasing the initial prestress force by 5% causes about a 10% decrease in the initial camber.
Initial losses	Initial prestress losses mainly consist of seating, elastic shortening, and relaxation after the preliminary tensioning to the bonding time of the concrete.	The overestimation of the initial prestress losses leads to a decrease in the camber; decreasing the initial losses by 10% causes about a 1% increase in the initial camber.
Support conditions	The location of supports in the storage area affects the field camber measurement.	Placing the storage supports at distance equal to the girder height from the end of the girder leads to an increase in the initial camber values by about 14%.
Using gross properties of the beam	The gross properties are calculated based on concrete only, ignoring the reinforcement and the prestressing strands. MoDOT suggests using the transformed properties of the beam in the camber calculations.	Change in camber less than 2% if gross used instead of transformed.
Temperature	Nguyen et al. (2015) investigated the influences of temperature variation on the girder camber.	Temperature variation of 20 degrees F results in an increase in the camber measurement by about 23%.
Concrete age/strength at strand release	This time affects the initial camber as well as the final camber calculations.	The variation in the initial strength and concrete age at release affects the camber measurements, so the camber calculation should be revised after measuring the compressive strength at the time of release.
Concrete density	The concrete density affects the dead load deflection.	Decreasing the concrete density by 5% results in an increase in the camber measurement by about 3%.

Project D - Use of Non-Proprietary Ultra-High Performance Concrete in Idaho Bridges

Research Project Description

This project focuses on applying non-proprietary ultra-high performance concrete (UHPC) in diverse applications across Idaho bridges, including closure pours in new structures, thin deck overlays, and retrofit initiatives like column repairs. The plan incorporates a comprehensive literature review of existing non-proprietary UHPC mix designs developed in the United States, considering locally available materials in Idaho and domestic products, such as steel fibers. Furthermore, the project involves experimental processes to formulate optimal mix designs, offer on-site mixing guidelines, and determine the best placement practices for non-proprietary UHPC materials.

Literature Review

UHPC is a cementitious material that possesses superior strength and durability in contrast to traditional concrete. The mixture uses Portland cement, fine aggregates, silica fume, and, in most cases, steel fibers. A comparison is shown in Figure 2.20 (HiPer Fiber 2023).

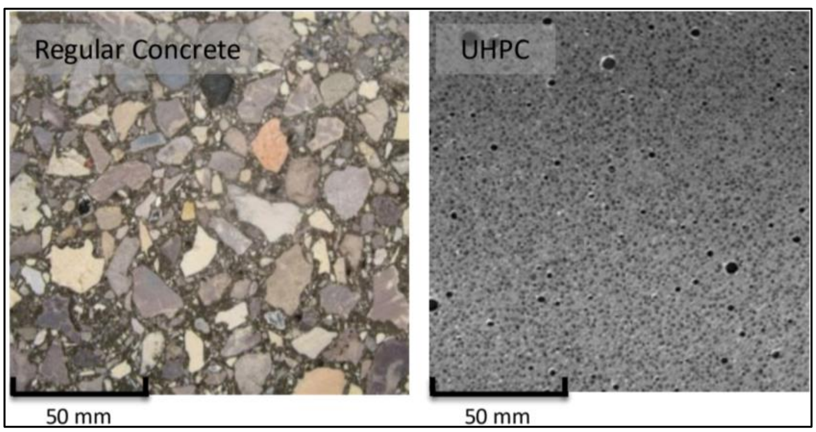


Figure 2.20 Conventional concrete versus UHPC (HiPer Fiber 2023).

The following sections present a literature review on the development and use of non-proprietary UHPC for bridge applications. In particular, the research documents that have been published in the last 10 years are considered.

FHWA 2013 – A project for the Federal Highway Administration (2013) by Wille and Boisvert-Cotulio at the University of Connecticut was one of the first attempts to encourage more use of ultra-high performance concrete (UHPC) in the United States. The goal was to develop a cost effective non-proprietary UHPC with a minimum compressive strength of 20 ksi, tensile strength of 0.72 ksi, and good durability properties. Materials from three regions were used; these were (1) the New York, Connecticut, New Jersey area, (2) the Upper Midwest near Iowa, Minnesota, and Michigan, and (3) the Northwest in the vicinity of Washington and Oregon. At the time of the report (2013), the cost of proprietary UHPC including fiber and delivery was about $2,000 per cubic yard, about 20 times the cost of conventional concrete at about $100 per cubic yard.

Since adding steel fibers to the mix increased the cost per cubic yard by about $470, Wille and Boisvert-Cotulio focused on UHPC without fibers. The locally available materials in the three regions included a list of cements (12 types), silica fumes (5 types), supplemental materials (13 types), high-range water reducers, HRWRs (8 types), and aggregates (10 variations). Four types of aggregates were selected: quartz (Q), basalt (B), limestone (L), and volcanic rock (VR). Q can be ordered in different regions of the United States. B was selected from the Northeast, L from the upper Midwest, and VR from the Northwest. Two different mixes were prepared; one set with fine aggregates only, and one with both fine and coarse aggregates. Table 2.22 shows optimum UHPC mixes with only fine aggregates, along with their corresponding costs summarized in the last row of the table. The costs, in 2013 dollars, ranged between $472 and $652 per cubic yard.

Table 2.22 UHPC mixtures with fine aggregates only and no fibers (FHWA 2013).

Material / Topic (lb/cy)	UHPC-1 (B; Northeast)	UHPC-2 (L; Upper Midwest)	UHPC-3 (VR; Northwest)	UHPC-4 (Q; United States)
White cement (lb/cy)	1,311	1,268	1,256	1,248
Silica fume (lb/cy)	328	317	314	312
Fly ash (lb/cy)	318	308	305	303
HRWR (lb/cy)	48	46	45	45
Fine aggregate (75µm-1.2mm)(lb/cy)	1,966	1,903	1,884	1,871
Aggregate-to-cement ratio	1.5	1.5	1.5	1.5
w/c ratio	0.23	0.24	0.23	0.23
Spread (inch)	11.4	10.4	11.3	12.4
Average compressive strength at 28 days (ksi)	26.9	24.1	23.5	29.0
Cost ($/cy)	494	472	496	652

Washington State DOT 2016 – In order to promote the use of precast decked members, such as deck bulb tees, and give the option of a more economical material for jointing such members, the researchers at Washington State University developed a UHPC mix using locally and domestically available materials (Washington State DOT 2016). Available materials included Type I/II Portland cement, sand, silica fume, HRWR, and domestic steel; however, expensive materials such as quartz powder and imported fibers were not included in the trial mixes. A breakdown of the resulting UHPC mix proportions are shown in Table 2.23. Based on workability, two of the mixes (A4 and C3) were selected for further testing.

Table 2.23 UHPC mix proportions (Washington State DOT 2016).

Mixture Type	Unit	A1	A2	A3	A4	A5	B1	B2	B3	B4	C1	C2	C3
Type I/II Portland Cement	lb/cy	1500	1475	1500	**1500**	1500	1450	1390	1278	1500	1620	1560	**1500**
Silica Fume	lb/cy	375	150	375	**375**	375	195	190	320	375	260	260	**260**
Fine Sand	lb/cy	1396	1823	1297	**1355**	1374	1864	1906	1860	1436	1463	1521	**1574**
Steel Fibers	lb/cy	267	197	267	**240**	267	197	197	197	237	236	236	**236**
HRWRA	gal/cy	7.0	7.0	7.0	**7.0**	8.0	8.7	9.0	9.5	9.0	9.5	10.5	**11.5**
Water	lb/cy	375	330	413	**394**	375	288	290	280	347	347	335	**325**
w/cm		0.20	0.20	0.22	**0.21**	0.20	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Spread Testing	in.	6.50	7.00	7.75	**9.00**	7.75	5.00	6.00	5.50	5.75	7.25	8.00	**9.50**

Experimental tests incorporated a range of assessments, including flow, compressive strength, modulus of rupture (flexural strength), modulus of elasticity, splitting tensile strength, direct tensile strength, autogenous shrinkage, drying shrinkage, restrained shrinkage cracking, and rebar pullout. The results from these experiments showed that, in general, the C3 mixture had superior mechanical performance. Consequently, this mix was recommended for use in the second phase of the project that involved large-scale structural testing and evaluation at the University of Washington.

Montana DOT 2017 – Sponsored by the Montana Department of Transportation (MDT), this project sought to formulate and characterize non-proprietary UHPC mix designs using locally accessible materials. The completion of this project would allow for a cost-effective concrete that utilizes traditional UHPC properties (Montana DOT 2017). Upon completion, the Montana Department of Transportation intends to implement this new non-proprietary UHPC mix design in their construction practices, including field-cast joints between precast concrete deck panels and between flanges of adjacent girders.

To achieve a non-proprietary UHPC mix that meets design goals of 8-inch flow and 20 ksi 28-day compressive strength, the following steps were taken:

1. A literature review of relevant UHPC material properties and behaviors was conducted.
2. A series of small trial batches were created with varying concrete constituents.
3. Analytical regression models were devised to predict the effects of the various constituents within the trial batches.
4. Once constituents, water-to-cement ratio, and sand-to-cement ratio were optimized, a new realistically sized batch was constructed to investigate the effects of including steel fibers.
5. The mixes were then modified to reach design goals and the mechanical and durability performance of the mix was investigated.

Ultimately this report found that suitable materials can easily be found within Montana to produce non-proprietary UHPC that met design goals. Some noteworthy insights resulting from this project for material acquisition and batch creation include:

- The physical makeup of the sand used in UHPC has a large effect on UHPC performance, so special consideration must be taken with respect to sand contaminants.
- Class C fly ashes may not be usable for UHPC due to its self-cementitious nature that accelerates set time and reduces workability.
- The most difficult to find and expensive materials used in the resulting mix were silica fume and HRWR.
- Batch size and mixing methods were observed to have a crucial impact on plastic and hardened concrete properties.
- Moderate variability was found between identical batches. The author expects to reduce this variability by including steel fibers, modifying curing procedures, and adjusting the cylinder preparation technique for batch mixing.
- Mixes that met design goals were found to be less than $1,000/yd^3 using materials found within Montana.

A regression analysis was used to determine the impacts of mix constituents and optimize the mixes. Using this regression analysis, four batches were found to meet the design criteria as shown in Table 2.24.

Table 2.24 Optimized mix summary and results (Montana DOT 2017).

Mix	w/c Ratio	SF/FA Ratio	HRWR/c Ratio	Flow (inches) Predicted (95% CI)	Flow (inches) Measured	7-day *f'c* (ksi) Predicted (95% CI)	7-day *f'c* (ksi) Measured	28-day *f'c* (ksi) Predicted (95% CI)	28-day *f'c* (ksi) Measured	56-day *f'c* (ksi) Predicted (95% CI)	56-day *f'c* (ksi) Measured
3M1	0.236	0.38	0.042	11 (8.9 to 13.1)	12	11 (8.2 to 13.8)	13	11 (7.0 to 15.0)	16.2	11 (9.2 to 12.9)	16.9
3M2	0.237	0.31	0.046	11 (8.2 to 13.8)	11.25	14.6 (10.9 to 18.3)	14.1	19.4 (15.1 to 23.7)	18.2	21 (17.5 to 24.5)	18.2
3M3	0.274	0.43	0.043	11 (7.0 to 15.0)	12.5	16.3 (11.0 to 21.6)	14.4	20.7 (14.6 to 26.9)	18.2	21 (15.9 to 26.0)	20.4
3M4	0.216	0.68	0.049	11 (9.2 to 12.9)	10.5	15.2 (12.7 to 17.6)	11.2	19.1 (16.2 to 22.0)	15.1	20 (17.6 to 22.3)	18.6

FHWA 2018 – Haber, et al. (FHWA 2018) conducted a study at FHWA's Turner-Fairbank Highway Research Center on six commercially available "UHPC-class" materials (U-A, U-B, U-C, U-D, U-E, and U-F). The goal was to provide extensive UHPC performance data to facilitate use in bridge applications. U-A was a laboratory-developed non-proprietary UHPC created in the United States; however, the other five UHPC-class materials were proprietary UHPC developed in Europe, U.S., and Canada. These materials were evaluated using 14 different ASTM, AASHTO, and FHWA-TFHRC-developed test methods. Study results indicated that all six materials behave similarly with respect to compressive strength, tensile strength, and durability, but vary with respect to other properties such as bond to precast concrete.

U-A non-proprietary UHPC contained Class H oil well cement, fine silica sand, finely ground quartz flour, amorphous micro-silica (silica fume), a polycarboxylate-type superplasticizer, steel fiber reinforcement, and water. Table 2.25 outlines the recommended mix proportions for U-A as suggested by the developer, while Figure 2.21 shows the compressive strength gain for all six materials considered in the study, including U-A. U-A's compressive strength reached approximately 18 ksi in 28 days.

Table 2.25 Recommended mix proportions for U-A (FHWA 2018).

Constituent	lb / yd^3	kg / m^3	Percentage by Weight
Cement	1,328	788	31.5
Silica Sand	1,288	764	30.5
Ground Quartz	367	218	8.7
Silica Fume	518	307	12.3
Superplasticizer	23	14	0.5
Water	278	165	6.6
Steel Fibers*	416	247	9.9

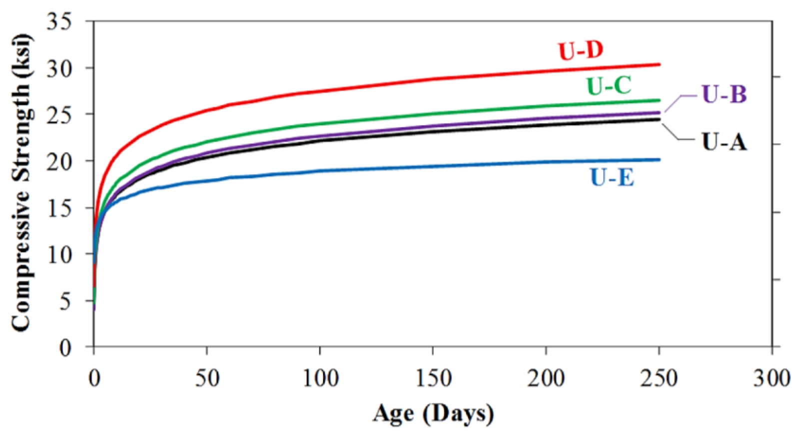
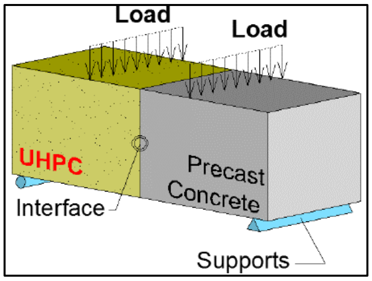
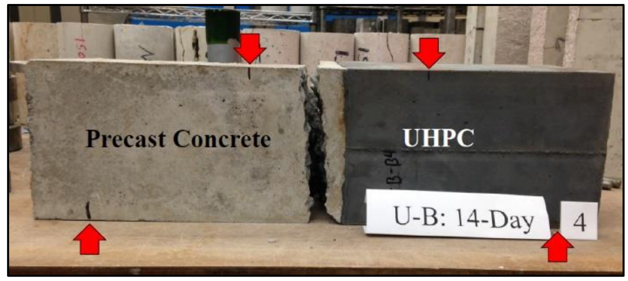


Figure 2.21 Compressive strength gain trendlines for UHPCs with 2 percent fiber (FHWA 2018).

One of the tests in the study by Haber et al. (FHWA 2018) was the interface bond strength between precast concrete and UHPC using a flexural beam test, following ASTM C78 (2022). This test was originally designed for measuring the modulus of rupture of concrete using a uniform 6 in. x 6 in. x 21 in. specimen in four-point bending. The specimen was altered to test for interface bond strength by joining 28-day precast concrete with UHPC of equal length, ensuring a common surface of exposed aggregate finish. This specimen was then subjected to four-point bending, shown in Figure 2.22(a). The precast portions had a compressive strength of 6 ksi (with an average measured value of 6.17 ksi). Since all test specimens failed in the precast concrete portion, shown in Figure 2.22(b), the true bond strength of the interface was not identified. This is problematic when the precast bridge deck or girders have higher compressive strength (e.g., 9 ksi or more), which is often the case.



(a)



(b)

Figure 2.22 (a) Flexural test based on ASTM C78, (b) photo after failure (FHWA 2018).

Michigan DOT 2018 – In the first phase of a project completed by El-Tawil, et al. at the University of Michigan, a non-proprietary UHPC was developed. While this non-proprietary UHPC showed promise under lab conditions, it encountered challenges during field implementation. These challenges included (1) increased the water demand due to the higher carbon content of the field silica fume (2) dosage of high range water reducer (HRWR) was inadequate, and (3) the field mixer was not able to properly mix the material. The second phase aimed to address these issues using local materials, optimizing the mix proportions and better field mixing the UHPC (Michigan DOT 2018). A series of mixes with components sourced from a variety of local suppliers were developed. The mix constituents were cement, ground granulated blast-furnace slag (GGBS), silica fume, HRWR, sand and steel fibers. Although white Portland Type I cement is preferred for UHPC due to its low water demand, the researchers used ordinary Portland cement Type I for its lower cost. To address the water demand issue, cement with tricalcium aluminate (C3A) content less than 8% and lower fineness was selected. The researchers also recommended partially replacing cement with GGBS in order to improve workability and reduce air voids in the mix.

One of the mixes developed in this study was used in a bridge restoration project in Michigan. The repair involved using UHPC for the joints connecting the reinforced concrete slabs shown in Figure 2.23. The field UHPC mix had an average 28-day compressive strength of 21.5 ksi and a tensile strength of 1.2 ksi. The reported material cost, in 2017 dollars, was $890 per cubic yard.

(a)

(b)

Figure 2.23 (a) Closure pour, and (b) UPHC placement (Michigan DOT 2018).

Nebraska DOT 2020 - This research focused on developing a non-proprietary UHPC mix for cost-effective and high-performance bridge construction in Nebraska using locally available materials (Nebraska DOT 2020). Key findings include:

- Successful production of UHPC using local fine silica sand (No. 10), Type I/II cement, slag, silica fume, modified polycarboxylate-based high-range water-reducing admixture (HRWR), and micro steel fiber.
- A mix design with 8% (by mass of binder) silica fume, 30% (by mass of binder) slag, and a total binder content of approximately 1900 pounds per cubic yard, is recommended for optimal UHPC properties. The final mix design for this project is shown in Table 2.26.

Table 2.26: Final mix design (Nebraska DOT 2020).

Mix ID	Cement	Silica Fume	Slag	Water	Sand	Fiber	HRWR	w/b
UHPC 1900	1214	162	588	310	1612	266	55.6	0.178

- Flow test and field-scale connection casting showed sufficient flowability and stability of the developed UHPC mix.
- Adequate mechanical properties, including satisfactory 28-day strength at 17.8 ksi and 56-day strength at 20.0 ksi, along with modulus of elasticity, Poisson's ratio, flexural strength, splitting strength, tensile strength, direct shear strength, slant shear strength, and bond strength comparable to commercial UHPC products.
- Satisfactory durability properties, including mass loss of less than 1%, negligible change in restrained shrinkage test, low chloride ion penetration based on surface resistivity test, and no cracking in the restrained shrinkage test.
- The authors recommend a high-shear pan mixer for field production, emphasizing the need for special batching and mixing procedures to ensure successful production.
- Consistency of the mixture depends on various factors, suggesting potential adjustments for desired consistency.
- A laboratory structural test with a field-scale UHPC bridge connection demonstrated that the developed UHPC provides similar structural capacity compared to commercial UHPC.

US DOT 2020 – This report presents a comprehensive study on the design of non-proprietary UHPC mixes (US DOT 2020). It begins by reviewing global research on non-proprietary UHPC development and theoretical particle packing models to formulate base mixes. The mixes are then refined by adjusting constituent ratios, aiming for strength properties comparable to commercial UHPC. Cost-effective base mixes are identified and extensively tested for strength, transport properties, volume stability, and freeze-thaw resistance. The results indicate that the developed non-proprietary mixes exhibit properties similar to proprietary ones as shown in Table 2.27.

In the latter section of the project, the selected mixes are evaluated for flexural strength, with a focus on the role of steel fibers. Various steel fiber types, shapes, sizes, and dosages are examined, shown in Figure

2.24 and Table 2.28, revealing that an optimal combination of micro- and macro-fibers enhances flexural strength. Considering the significant cost of steel fibers, the report explores the potential of replacing them with synthetic fibers. Five types of synthetic fibers are tested, demonstrating promise in flexural strength and post-cracking behavior. The report concludes by providing cost-effective non-proprietary UHPC mixtures using steel fibers, offering recommendations for optimal fiber combinations, and suggesting the use of synthetic fibers as partial replacements. Overall, it offers insights into designing and utilizing non-proprietary UHPC mixes for transportation infrastructure applications.

Table 2.27: Results of fresh, strength, and transport properties (US DOT 2020).

Mixture	NP1	NP2	NP3	NP4	NP-HSF	NP-MS	P1	P2
Flow (mm (in.))	216 (8.5)	216 (8.5)	203 (8.0)	229 (9.0)	216 (8.5)	203 (8.0)	216 (8.5)	216 (8.5)
7-Day Compressive Strength (MPa (ksi))	97.2 (14.0)	97.9 (14.2)	86.9 (12.6)	77.2 (11.2)	71.7 (10.3)	101.4 (14.7)	117.2 (16.9)	100.7 (14.6)
Split Tensile Strength (MPa (ksi))	10.1 (1.5)	10.6 (1.5)	10.6 (1.5)	10.3 (1.5)	11.0 (1.6)	11.8 (1.7)	14.5 (2.1)	12.0 (1.7)
Resistivity (kΩ-cm)	8.0	8.5	9.7	6.1	25.7	20.2	60.0	23.5
Ultimate Autogenous Shrinkage (x10^{-6} m/m (in/in))	280	240	400	260	980	370	477	322
Ultimate Drying Shrinkage (%)	0.110	0.135	0.124	0.110	0.148	0.125	0.110	0.124

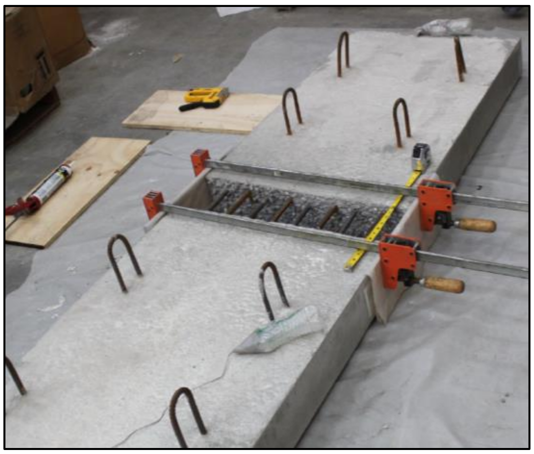
(a) (b) (c)

Figure 2.24 (a) Straight microfibers, (b) twisted wire fibers, and (c) hooked macro-fibers (US DOT 2020).

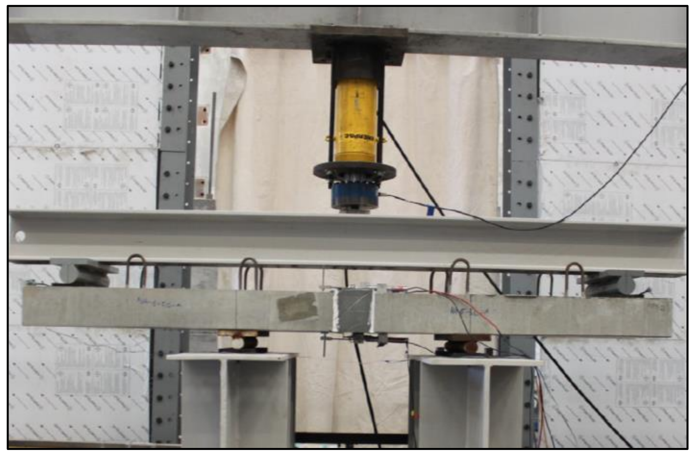
Table 2.28 Properties of tested steel fibers (US DOT 2020).

Steel Fiber Type	Length	Diameter	Tensile Strength
Straight microfibers (S)	0.5 in. (13 mm)	0.008 in. (0.20 mm)	290 ksi (2,000 MPa)
Twisted wire fibers (W)	1 in. (25 mm)	0.02 in. (0.5 mm)	246.5 ksi (1,700 MPa)
Hooked macrofibers (H)	1.37 in. (34 mm)	0.021 in. (0.54 mm)	159.5 ksi (1,100 MPa)

Georgia Tech 2021 – In a project for Georgia Department of Transportation (GDOT), Lim (2021) developed a non-proprietary UHPC mix using locally available materials that met the GDOT's minimum required 28-day compressive strength of 18 ksi and tensile strength of 0.75 ksi. The mix consisted of Type I cement, Class F fly ash, metakaolin, masonry sand, HRWR, and steel fibers that are available in the state of Georgia. Metakaolin and Type F fly ash were used as supplementary cementitious materials (SCMs) instead of silica fume. In addition, as shown in Figure 2.25, 6-inch-thick deck panels that were joined by the lab-developed UHPC were experimentally assessed. The precast interfaces were prepared to have an exposed aggregate finish. Deck panels had a 28-day specified compressive strength of 6 ksi with estimated cracking, yield and ultimate moments of 8.9 k-ft, 26.3 k-ft, and 27.5 k-ft, respectively. The UHPC connection showed no cracks until the yield moment was reached. Cracks at the interface between UHPC and concrete occurred at lower loads than the yield moment, but no debonding was observed. The steel reinforcing bars yielded before connection failure, indicating satisfactory behavior of the deck panel specimen with the non-proprietary UHPC connection.



(a)



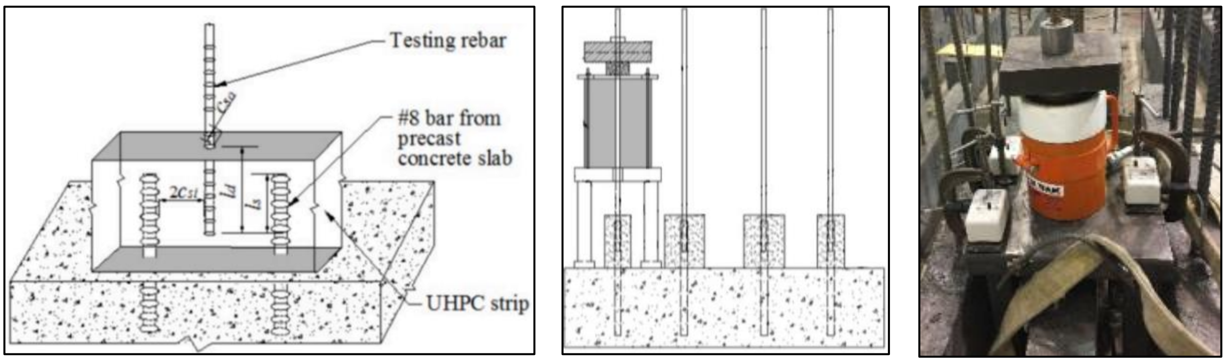
(b)

Figure 2.25 (a) deck panel prior to placement of UHPC, and (b) deck panel test (Lim 2021).

Montana DOT 2021 - This project continued with the investigation started in Phase I, looking to develop a non-proprietary UHPC mix that can be used in field-cast joints for precast concrete deck panels (Montana DOT 2021). Phase I of this project focused on the creation of the non-proprietary UHPC mix whereas, Phase II focused on (1) testing the possible variability in concrete performance resulting from differences in concrete constituents, (2) exploring issues related to field batch and mixing, and (3) investigating rebar bond strength.

For Task 1, testing variations in the source of constituent materials yielded minor variation in concrete performance. For Task 2, testing the impact of differing batch sizes showed that the batch size did not significantly change the concrete performance, but it did require 10% more water and HRWR at larger scales. Increasing temperatures showed the largest change in performance, namely in flow and compressive strength. It is suggested that care be given to batches being mixed at higher temperatures. For Task 3, to test the bond behavior of the rebar to the UHPC, a UHPC curb was connected to a conventional concrete slab with two separate pieces of rebar adhering to standard FHWA dimension recommendations. A third piece of rebar was cast into the top and a hydraulic pump was used to pull on the top rebar, shown in Figure 2.26. The rebar displacement was measured using three string potentiometers.

This test found that all reinforcing bars reached their yield stress prior to bond failure, showing that the minimum FHWA recommendations for embedment depth and clear cover are suitable for these conditions.



(a) (b) (c)

Figure 2.26 (a) Test specimen and key dimensions, (b) idealized test setup, (c) actual test setup and instrumentation (Montana DOT 2021).

Montana DOT 2023 - This project was the last phase of a three-phase research project. This phase focused on implementing the newly developed non-proprietary UHPC in field-cast joints for precast concrete bridge deck panels for two bridges in Montana (Montana DOT 2023). This was done in a 4-step process where (1) constituent materials selected by the contractor were approved, (2) implementation-related, namely the mixing process, research was conducted, (3) trial batches were mixed and used in mock bridge joints for testing, and (4) the non-proprietary UHPC was implemented and monitored. The newly designed non-proprietary UHPC was used for all field-cast connections, including:

1. Pile to pile cap
2. Beams and pile caps
3. Wing wall connections
4. Longitudinal shear-keys between adjacent beams

The bridge construction consisted of demolition and site preparation, placement of pile caps, installation of longitudinal beams, and keyway grinding, shown in Figure 2.27.

The material and labor cost for the Montana UHPC (MT-UHPC) used in this bridge construction was found to be $4,560 per cubic yard, as outlined in Table 2.29.

(a)

(b)

(c)

(d)

Figure 2.27 (a) Bridge site after removal of existing bridge, (b) pile cap placed on steel piles, (c) second beam element placed on pile caps, and (d) keyways after removal of wood slats, prior to grinding (Montana DOT 2023).

Table 2.29 Cost of MT-UHPC per cubic yard (Montana DOT 2023).

Item	Cost/cy
Cement	$ 237
Silica Fume	$ 174
High Range	$ 204
Fly Ash	$ 68
Steel Fibers	$ 790
Sand	$ 77
Materials Subtotal	**$ 1,550**
Mixing/Packaging	$ 850
Total Material Cost	**$ 2,400**
Grinding	$ 370
Placement	$ 1,790
Total	**$ 4,560**

Approximately thirteen months after bridge completion, a site visit was done where bridges were inspected for signs of damage, with focus being on cracking, spalling, and debonding. While no significant damage was observed in the MT-UHPC, the pile cap to pile connections were not visible and could not be visually inspected. The only sign of deterioration was in the form of surface rust in the steel fibers embedded in the MT-UHPC and on the pipes used to connect the beam deck elements to the pile caps. Since the MT-UHPC was grinded down, exposing the steel fibers, it was assumed that the rust was only surficial. From other outside research on the propagation of rust under these circumstances, it was deemed that this rust would not propagate to other steel fibers.

Idaho State University 2023 – At Idaho State University, Ali Shokrgozar (2023) developed a non-proprietary UHPC using locally available materials in Idaho and compared its properties with a commonly used proprietary UHPC. The materials were to be used in closure pour connections between Deck Bulb-T girders as shown in Figure 2.28. The materials used were fine aggregates, Portland cement Type I/II, silica fume, Type F fly ash, HRWR, and domestically sourced steel fibers.

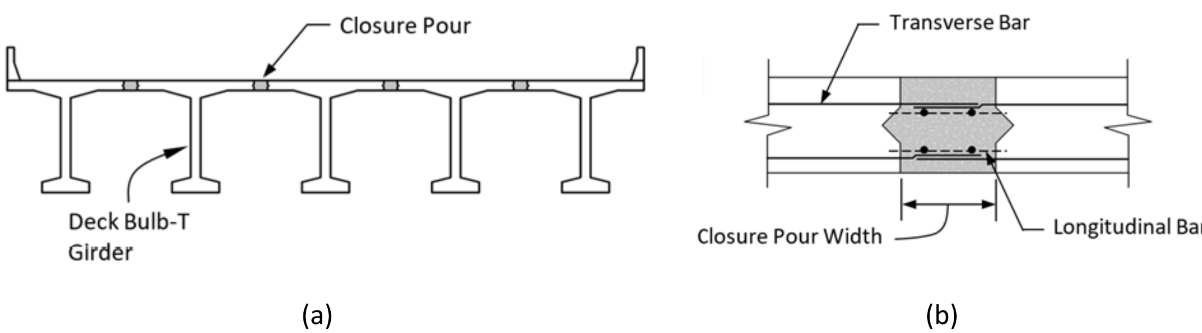


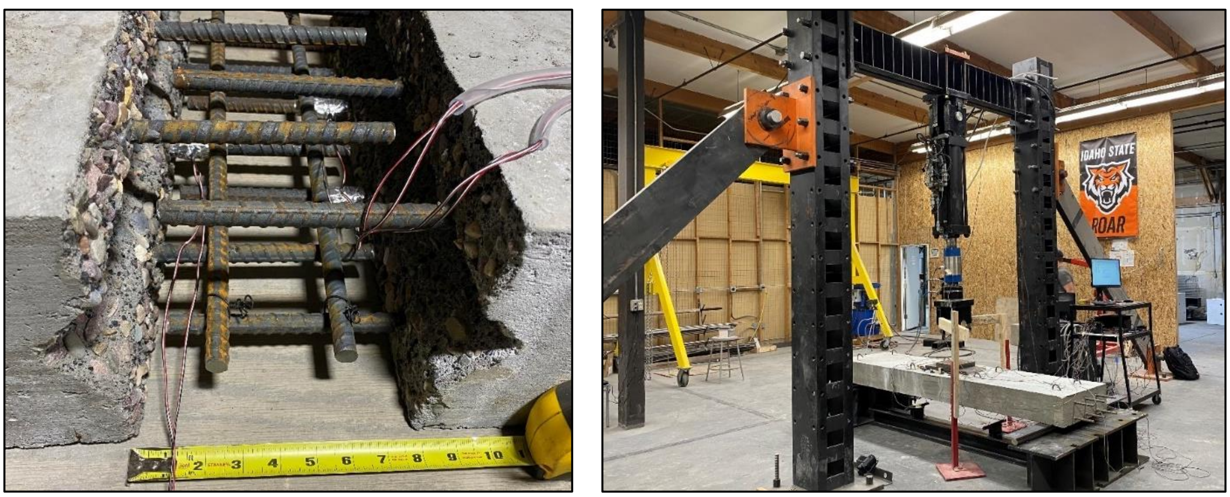
Figure 2.28 (a) Deck Bulb-T girders, and (b) closure pour detail (Shokrgozar 2023).

As shown in Table 2.30, standard tests were performed for both non-proprietary and proprietary UHPC with comparable results. Among these tests was the examination of interface bond strength between UHPC and precast concrete (see Figure 2.29). Unlike interface bond tests performed by Haber et al. (FHWA 2018) where 6 ksi precast concrete was used, Shokrgozar considered interface bonds with 8 ksi, 10 ksi, and 12 ksi concrete. In this study, all failures occurred at the interface between precast concrete and UHPC and a directly proportional relationship between the specimen bond strength and the precast compressive strength was observed. The average values of interface bond strength are shown in Table 2.30.

Table 2.30 Material comparison (Shokrgozar 2023).

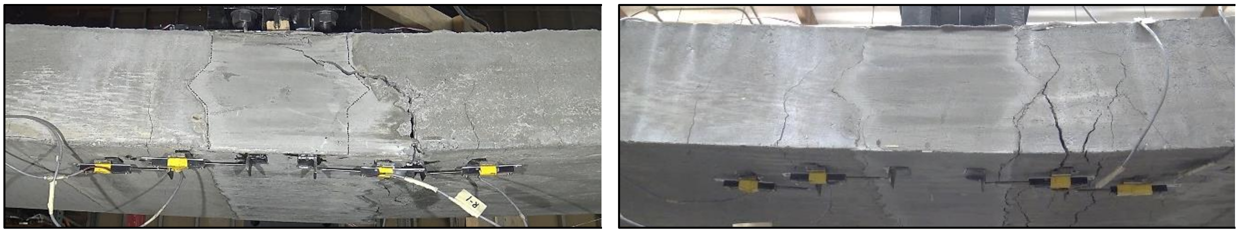
	Non-proprietary UHPC	Proprietary UHPC
Flow Table Test, in	10	10
Compressive Strength, ksi	18.1	20.1
Tensile Strength, ksi	2.8	2.9
Average Interface Bond Strength with Precast Concrete with 8 ksi, 10 ksi, and 12 ksi, psi	651	696
Shrinkage (336 days), micro-strain	290	410
Modulus of Elasticity, ksi	6,950	7,370
Poisson's Ratio	0.19	0.2
Bridge Deck Connection Ultimate Moment, k-ft	61	67
Material Cost per yd^3 (labor cost not included)	\$350	\$2,000

In addition, large-scale tests were performed on precast panels with both non-proprietary and proprietary UHPC as the closure pour materials. Panels were 24 in. wide by 8 in. thick and reinforced with No. 5 bars; see Figure 2.29(a). The loading is shown in Figure 2.29(b). In both cases, the panel steel bars yielded before the ultimate moment was reached. The ultimate moments were 61 k-ft and 67 k-ft for panels with non-proprietary and proprietary UHPC, respectively. The panels at ultimate loads are shown Figure 2.30.



(a) (b)

Figure 2.29 (a) Closure pour connection, (b) test setup (Shokrgozar 2023).



(a) (b)

Figure 2.30 Panels at ultimate load with (a) non-proprietary, and (b) proprietary UHPC (Shokrgozar 2023)

Project D is focused on testing these non-proprietary UHPC mix designs for bridge applications, since the focus was developing mix designs from Idaho-based resources. This should lower overall costs related to its utilization.

Project E – The Impacts of Type IL Cement on Bridge Structures

Research Project Description

The bridge structures industry has undergone a significant transition, moving away from traditional Type I/II cement towards the utilization of Type IL, commonly known as Portland-Limestone Cement (PLC). This can be seen in a 2022 DOT survey shown in Table 2.31 and Table 2.32 (survey responses are unedited). In Europe, it has been effectively utilized for a minimum of thirty years. Since 2012, it has been marketed in the US as a Type IL cement containing 5% to 15% inter-ground limestone fines in accordance with ASTM C5952/AASHTO M2403, the Standard Specification for Blended Hydraulic Cements, for use in transportation infrastructure. In Canada, since 2008, cement containing up to 15% limestone particles has been permitted. This shift marks an advancement in construction materials, with PLC offering several advantages over its predecessors, including enhanced sustainability and improved performance characteristics.

This project aims to delve into a comprehensive review and analysis of the specific impacts that PLC has on bridge structures. By examining various aspects such as durability, strength, environmental sustainability, and long-term performance, the study seeks to provide valuable insights into the suitability and effectiveness of PLC in bridge construction projects.

Table 2.31 2022 DOT PLC Survey, Questions 1-4, and Corresponding Unedited Responses.

State	1. Does your state use Portland Limestone Cement (PLC) in or on Bridges?	2. Does your state use PLC in concrete pavement, or other items that are not bridges?	3. What is the maximum limestone content allowed for bridge work?	4. What is the maximum limestone content allowed for all other concrete items?
Alabama	"yes"	"yes"	"We allow up to 15% limestone. This is the maximum amount allowed per AASHTO M240/ASTM C595."	"We allow up to 15% limestone. This is the maximum amount allowed per AASHTO M240/ASTM C595."
California	"Yes"	"Yes"	"15% per ASTM C595 or AASHTO M240"	"same"
Colorado	"Yes Type IL is allowed. Not sure if it has been used since ready mixed suppliers haven't made the switch yet"	"Yes, since 2006 we have used PLC in PCCP."	"ASTM C595 limit of 15%"	"ASTM C595 limit of 15%"
Georgia	"GA DOT allows it"	"GA DOT allows it"	"Max 15%"	"Max 15%"
Idaho	"no, not specifically, but it has been used in concrete overlays, coping and other items."	"yes, for luminaire and signal foundations, among other items"	"15% per ASTM C595 or AASHTO M240"	"15% per ASTM C595 or AASHTO M240"
Illinois	"Yes"	"Yes"	"Nominally 15% per the limits in C595."	"Nominally 15% per the limits in C595."
Illinois Tollway	"Yes"	"Yes"	"15% since we reference ASTM C595/AASHTO M 240"	"15% since we reference ASTM C595/AASHTO M 240"
Indiana	"yes"	"yes"	"15% which is the maximum per AASHTO M240 for PLC. However, the PLC that we are receiving is 9-12% limestone"	"15% which is the maximum per AASHTO M240 for PLC. However, the PLC that we are receiving is 9-12% limestone"
Kentucky	"yes"	"yes"	"15% per AASHTO M240, most submitting about 12%"	"15% per AASHTO M240, most submitting about 12%"
Michigan	"Yes"	"Yes"	"Per ASTM C595, the range is 5% - 15%"	"Per ASTM C595, the range is 5% - 15%"
Minnesota	"Yes, we allow it in all concrete. MnDOT Specification 2401, Bridges and Structures. MnDOT Specification 3103, Blended Hydraulic Cement. http://www.dot.state.mn.us/pre-letting/spec/index.html"	"Yes. MnDOT Specification 2301, Concrete Pavement. MnDOT Specification 2461 Structural Concrete."	"15%"	"15%"
Missouri	"Yes"	"Yes"	"The Missouri DOT follows AASHTO M 240 which allows up to 15 percent replacement."	"The Missouri DOT follows AASHTO M 240 which allows up to 15 percent replacement."

State	1. Does your state use Portland Limestone Cement (PLC) in or on Bridges?	2. Does your state use PLC in concrete pavement, or other items that are not bridges?	3. What is the maximum limestone content allowed for bridge work?	4. What is the maximum limestone content allowed for all other concrete items?
Montana	"Yes"	"Yes"	"Currently IL(15) is the highest on our QPL. Per ASTM C595 PLC limestone content should be more than 5% and less than or equal to 15%."	"Currently IL(15) is the highest on our QPL. Per ASTM C595 PLC limestone content should be more than 5% and less than or equal to 15%."
Nebraska	"At this time we do not, we have changed our specifications to allow the use PLC in all concrete. Nebraska requires 25% F Ash in all concrete. We have ASR in this state."	"At this time we do not, we have changed our specifications to allow the use PLC in all concrete. Nebraska requires 25% F Ash in all concrete. We have ASR in this state."	"12%"	"12%"
North Dakota	"yes, NDDOT allows the use of PLC, it is pretty much the only cement now available in our market."	"yes"	"AASHTO M 240 Type IL (MS) governs it but I think industry is using around 11-12%"	"AASHTO M 240 Type IL (MS) governs it but I think industry is using around 11-12%"
Oregon	"Yes we allow the use in bridges"	"Yes we allow the use in all paving and structural concrete applications"	"Our limits are based on AASHTO M240"	"Our limits are based on AASHTO M240"
Tennessee	"Yes"	"Yes"	"If the chemical and physical tests pass M 240, then our specifications are written to allow the full 15% replacement. However, the majority of the sources we see target 10% replacement and vary between 8% and 12% replacement."	"If the chemical and physical tests pass M 240, then our specifications are written to allow the full 15% replacement. However, the majority of the sources we see target 10% replacement and vary between 8% and 12% replacement."
Texas	"Yes"	"Yes"	"15% Per ASTM C 595. Most approved Type IL cements in Texas generally contain about 10% limestone."	"Same."
Utah	"yes"	"yes"	"The specification allows up to 15%. Our two in-state providers are using 10% and 12%."	"The specification allows up to 15%."
West Virginia	"yes"	"yes"	"15% by mass of the blended cement"	"15% by mass of the blended cement"

Table 2.32 2022 DOT PLC Survey, Questions 5-8, and Corresponding Unedited Responses.

State	5. How long have you been using PLC in Bridges?	6. How long have you been using PLC on other items?	7. Have you noticed any benefits?	8. Have you noticed any deleterious effects?
Alabama	"PLC was incorporated into our specifications in December 2019"	"PLC was incorporated into our specifications in December 2019"	"The main benefit would likely be that it has been easily interchangeable with both Type I and II cements."	"We have not noticed or had any deleterious effects or negative impacts reported to us due to the usage of PLC."
California	"Since Oct 21"	"Since Oct 21"	"GHG reduction in cement production"	"None"
Colorado	"Not long as PLC is not common at ready mixed suppliers"	"Since 2006"	"Easier finishing"	"None"
Georgia	"GA DOT approved the use of Limestone Cement within the past few months."	"GA DOT approved the use of Limestone Cement within the past few months."	"To Be Determined"	"To Be Determined"
Idaho				
Illinois	"Largely effective this current construction season, though there may have been some pours last year."	"Largely effective this current construction season, though there may have been some pours last year."	"Nothing that has been verified or of enough significance to catch our attention."	"Nothing reported yet. I have heard a couple alleged instances of 'low' early strength, but again, nothing that has been verified yet or been raised to a level of concern by our districts or contractors/producers."
Illinois Tollway	"Earlier this year, probably about 4 months"	"We used PLC on some pavement in 2014 and then nothing until earlier this year"	"No (in terms of the physical properties of the actual concrete produced) There are environmental benefits to using PLC, but we don't quantify those at this time"	"No"
Indiana	"It has been allowed by the INDOT standard spec since 2015. However, it first began actual field use in 2021 and is now extensively used in 2022"	"It has been allowed by the INDOT standard spec since 2015. However, it first began actual field use in 2021 and is now extensively used in 2022"	"No"	"We are seeing many occurrences of low/slow strength this year. However, while PLC is suspected in some cases we have not proven any of the issues to be due to PLC"

State	5. How long have you been using PLC in Bridges?	6. How long have you been using PLC on other items?	7. Have you noticed any benefits?	8. Have you noticed any deleterious effects?
Kentucky	"it has been permitted but has not made it into the market until recently."	"it has been permitted but has not made it into the market until recently."	"not yet"	"not yet"
Michigan	"Its use began this construction season, 2022"	"Its use began this construction season, 2022"	"no"	"no"
Minnesota	"We have allowed its use since 2018, however it was not readily produced until this year. It has been used in bridges since the start of 2022."	"It was piloted on some paving projects in 2017 with no performance issues noted. It is currently being used in all concrete."	"Nothing that stands out at this point but we are still early in its use."	"None"
Missouri	"The Standard Specifications were changed in 2013 allowing the use of PLC to be used in structures and pavements."	"The Standard Specifications were changed in 2013 allowing the use of PLC to be used in structures and pavements."	"To date, the field performance has been comparable to concrete utilizing Type I cement. We have noticed that the finishing properties are enhanced when using PLC."	"To date, we have not experienced any performance issues utilizing PLC. The Missouri DOT built our first pavement using PLC in 2013."
Montana	"We have allowed the use of Type IL for some time but only started seeing it be used in the last year to year and a half."	"We have allowed the use of Type IL for some time but only started seeing it be used in the last year to year and a half."	"Not notably, have heard reports back that it performs very similar to ordinary Portland or slightly better in fresh state for placing and finishing."	"Not notably, have heard reports back that it performs very similar to ordinary Portland or slightly better in fresh state for placing and finishing."
Nebraska	"We haven't started at this point, the cement manufactures still have the Type I/II on hand."	"We haven't started at this point, the cement manufactures still have the Type I/II on hand."	"Our research has shown a slight increase in early strength."	"We have seen no issues with the PLC."

State	5. How long have you been using PLC in Bridges?	6. How long have you been using PLC on other items?	7. Have you noticed any benefits?	8. Have you noticed any deleterious effects?
North Dakota	“1 year”	“1 year”	“Have not noticed an effect other than the lower total strength at 28 days”	“Have not noticed an effect other than the lower total strength at 28 days. we have seen a drop of 200 to 400 psi in our standard paving mixes 28 day compressive strength. 5100psi 28 days vs 5300psi to 5500 psi.”
Oregon	“The first products were approved back in 2017, first use was around 3-4 years ago and use has steadily increased since then.”	“The first products were approved back in 2017, first use was around 3-4 years ago and use has steadily increased since then.”	“A slight reduction in water demand for some along with a slight increase in 28 day strengths, for other producers no difference from OPC”	“Nothing yet”
Tennessee	“The majority of our approved Type IL (10) sources have been added during/after Fall 2021. Our current database has activations as early as July 2018.”	“The majority of our approved Type IL (10) sources have been added during/after Fall 2021. Our current database has activations as early as July 2018.”	“No Comments to date.”	“No comments to date regarding material performance. As a tangent conversation, it has given rise to the need to educate our mix designers on the differences (Spec. gravity, strength gain, etc.).”
Texas	“Allowed in 2020”	“Allowed in 2014.”	“No. Similar performance to C150 cements.”	“No”
Utah	“A little over a year.”	“A few projects were run in 2009 and 2014 with good success. A little over a year ago our concrete suppliers in-state stopped producing II-V cement and went to PLC cement only. Attached is a CP tech brief on the use of PLC in Utah, Colorado and one other state.”	Yes, there are environmental benefits (less CO2) and our cement powder goes 10% farther. The suppliers blended the PLC to not give us much of a difference from our II-V cement.	“Not that we have noticed. There may be some slight differences.”
West Virginia	“7 Years”	“Around 7-8 Years“	“N/A”	“None”

Literature Review

This section outlines a moderate literature review on mechanical properties of Type IL cement considering research done in the past 10 years. In some cases, research was found that specifically outlines potential impacts of Type IL, or Portland-Limestone Cement (PLC), on transportation structures.

Cost et. al. 2013 – This project focused on comparing the strength performance, volume distribution, slump, and initial set time of PLC against Ordinary Portland Cement (OPC). To control for material variability from geographic locations, material variability from cement distributors, and supplementary cementitious materials (SCMs) effects, concrete was selected from five south-eastern state distributors in the United States each with four independent SCMs. Care was taken to ensure aggregate, admixtures, and proportions used in OPC and PLC were the same, only allowing for a difference in cement. The four used SCMs were 0% SCM, 25% Class C fly ash, Class F fly ash, and 40% slag cement. The five different sources A through E, each producing cement with varying limestone content and Blaine fineness, can be seen in Figure 2.31.

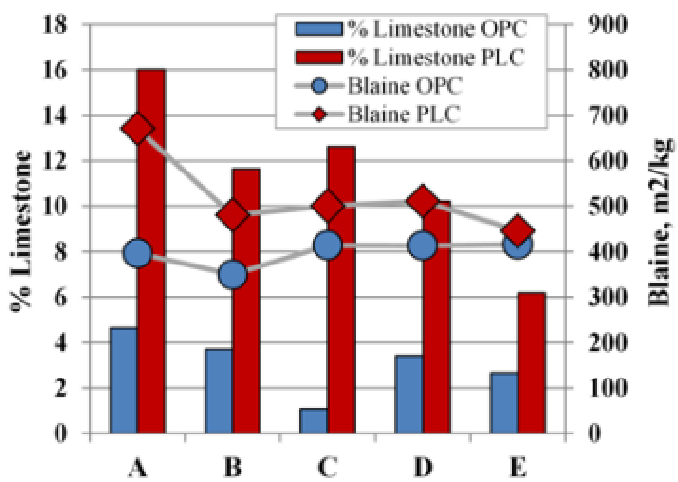


Figure 2.31 Limestone Content and Blaine Fineness Compared for Each Cement Sample, by Source (Cost et. al. 2013).

The results of this testing indicate that there are negligible differences in slump, initial set time, and concrete strength between OPC and PLC that use no SCMs, 25% Class C fly ash, Class F fly ash, and 40% slag cement. There were no indications of operational distinctions between OPC and PLC when using the four listed mixtures. In addition, the use of different SCMs influenced performance at a higher rate than cement type from the same source.

Georgia Department of Transportation 2016 – The Georgia Institute of Technology conducted research to compare Type IL cements that accommodate AAHSTO M 240, Standard Specification for Blended Hydraulic Cement, to Type I/II cements that accommodate AASHTO M 85, Standard Specification for Portland Cement, with a focus on precast prestressed bridge girders. The two different cements, along with the mortar and concrete they produced, were investigated to experimentally determine material characteristics, material properties, setting time, strength development, shrinkage, creep, permeability, and structural properties used for precast prestressed bridge girders. To control variability in materials from different sources, five suppliers were chosen to test simultaneously. In addition, to control for curing temperature, two curing conditions were used: room temperature (73°F) and high temperature (140°F). These curing conditions can be seen in Figure 2.32 and Figure 2.33.

Figure 2.32 Saturated Lime-water baths for Curing at Room Temperature (73°F) (Georgia DOT 2016).

Figure 2.33 Intellicure Temperature Controlled Curing Box for High Temperature (140°F) Curing (Georgia DOT 2016).

After testing beams with a 30-ft span, 8,000 psi design strength, and 270 ksi prestressing strands with both Type I/II and Type IL cements, it was found that prestress losses were 5% less than predictions using the refined method in the 2016 edition of AASHTO LRFD Bridge Design Manual. It was also discovered that predictions using the same manual resulted in measured strand transfer lengths of less than half and measured development lengths of less than 45%. The study concludes that the fineness of PLCs leads to increased shrinkage when compared to Type I/II cements if the water-cementitious materials ratio (w/cm) is larger than 0.45; however, when the w/cm is less than 0.4, there are no noteworthy differences. These results demonstrate that PLCs that accommodate AASHTO M 240 can be exchanged with Type I/II cements that accommodate AAHSTO M 85 for transportation structures.

Ain Shams University 2018 – In 2018 a study was done at Ain Shams University to explore the effect of adding limestone to reduce clinker content, leading to economic and environmental benefits. This study compares concrete properties of PLC and Ordinary Portland Cement (OPC). The results showed that PLC concrete performs competitively with OPC, with lower water permeability observed in all PLC concretes. To determine this, materials were batched according to the mix design and mixed in a pan type mixture. A slump test was chosen to measure workability of concrete mixtures, following ASTM C143, "Standard Test Method for Slump of Hydraulic-Cement Concrete". A heat of hydration test was carried out to measure heat evolution, and setting time was determined according to ASTM C403, "Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance", using penetration resistance measurements on mortar sieved from concrete. Specimens were cast into steel molds in three layers and compacted using a vibrating table. After curing, various tests were conducted including compressive strength tests on cubes, tensile strength tests on cylinders at 28 days, and flexural strength tests on beam specimens at 28 days according to relevant standards. Bond strength (pull-out test) was assessed using "lollipop" specimens at 28 days. Water penetration tests followed DIN 1048, a German standard titled "Testing concrete; testing of hardened concrete (cube specimens)", on plate-shaped specimens after 28 days of curing and can be seen on Figure 2.34.

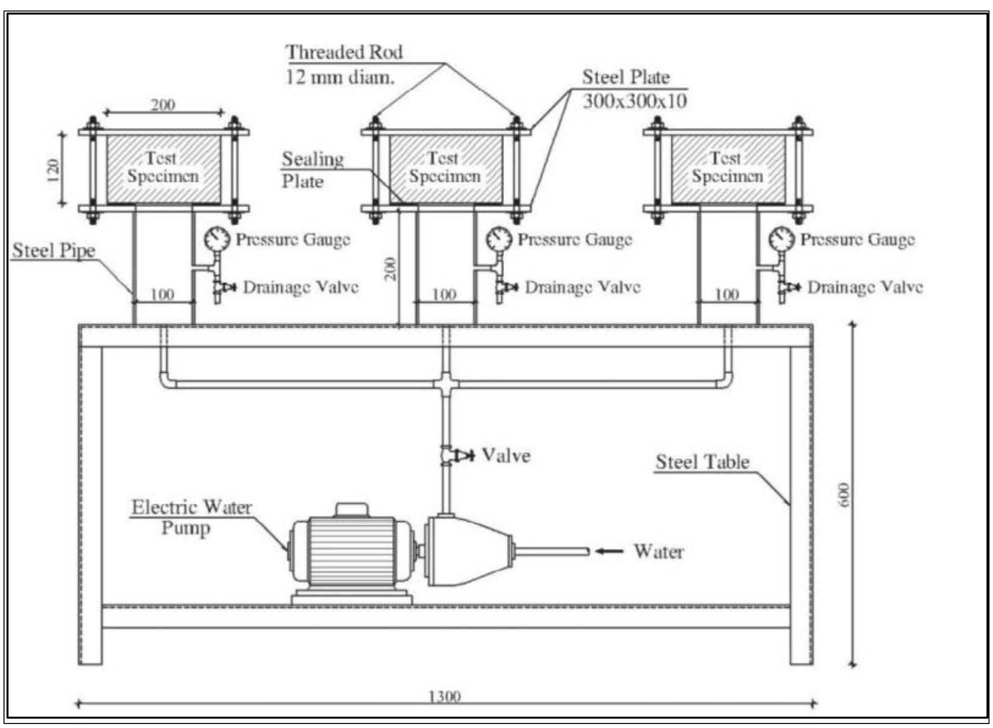


Figure 2.34 Testing Apparatus for Water Penetration Tests (Aim Shams University 2018).

Sulfate resistance tests involved immersing concrete cubes in sulfate solution for 90 days, and rapid chloride penetration tests evaluated concrete's resistance to chloride ion penetration over 6 hours. These tests were conducted to assess the effects of using locally produced PLC on concrete characteristics, demonstrating its competitive performance and potential for improved durability compared to OPC.

California State University 2022 – California State University in conjunction with the University of Texas at Austin examined the feasibility of producing strong, durable concrete with low clinker content, achieved by blending Portland limestone cement (PLC) with high limestone content and various supplementary cementitious materials (SCMs). Seven cements with limestone contents ranging from 3% to 31%, along with SCMs like fly ash, slag, and silica fume, were used in forty-two mixtures with different water-cementitious materials ratios. Mechanical properties and electrical resistivity were measured at different intervals. The study found that while compressive strengths were similar for mixtures with equivalent effective water-cementitious materials ratios, combining PLCs with SCMs in very low-clinker systems led to reduced compressive strength but increased electrical resistivity. These compressive strengths over time for each PLC is shown on Figure 2.35. Overall, the report concluded that strong, good-quality concrete can be produced while maintaining environmental benefits.

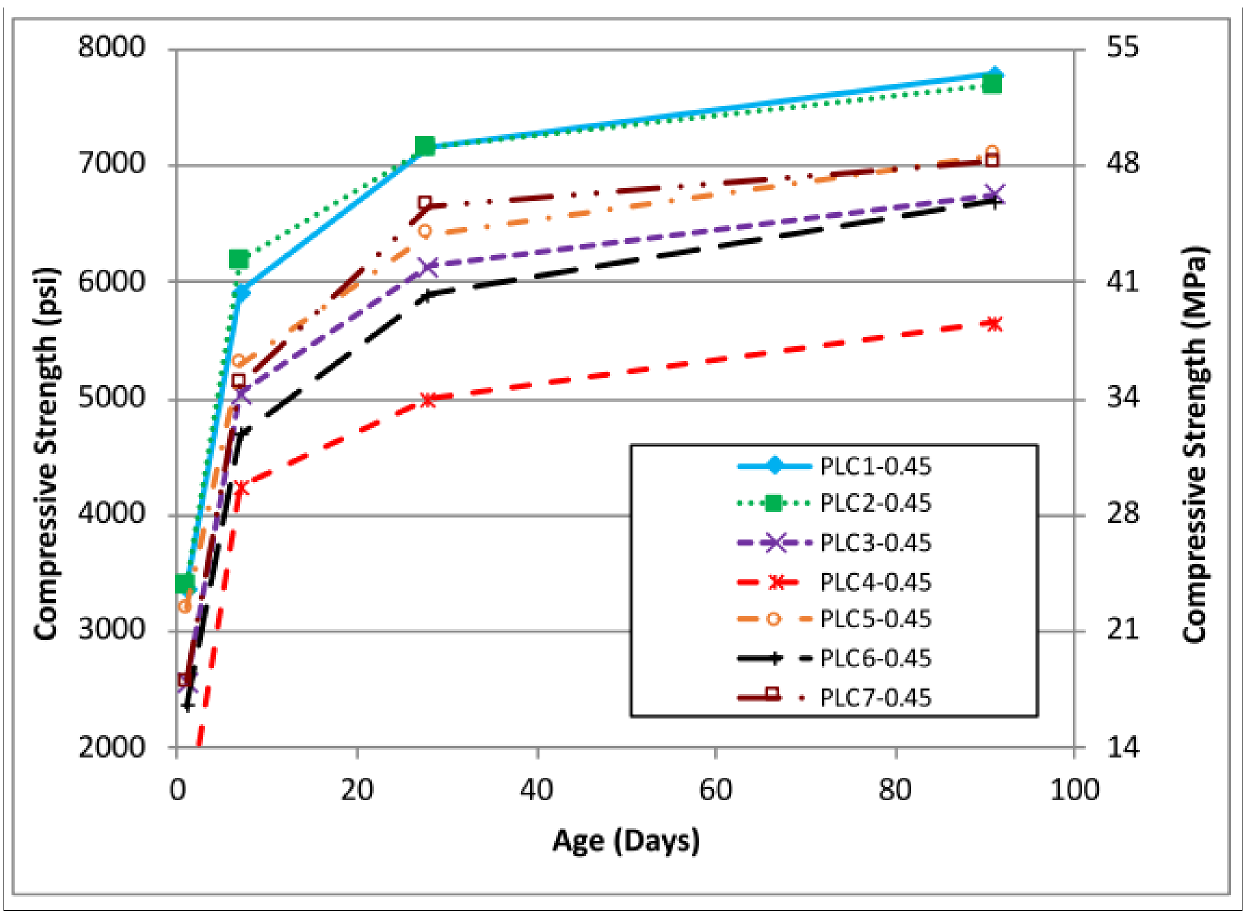


Figure 2.35 Compressive Strengths over time for cement mixtures at 45% w/cm (CSU 2022).

Choudhary et al. 2022 – One way to lower greenhouse gas emissions is to substitute limestone for some of the clinker in cementitious systems. The purpose of this study was to assess three performance criteria of Portland limestone cement (PLC) mixtures: flexural strength, drying shrinkage, and heat of hydration. Using Type II/V ordinary Portland cement (OPC), PLC, and OPC with ground limestone (OPC + LS), mortar and paste compositions totaling eighty were made, both with and without additional cementitious materials (SCMs). The PLC (ASTM C150, Standard Specification for Portland Cement, Type II/V) was manufactured in the same commercial facilities with the same raw materials as the OPC. The heat of hydration (extent of reaction) for the PLC and OPC + LS paste combinations was within 10% of the OPC paste mixtures, while the matching OPC-slag paste mixtures and PLC and OPC + LS paste mixtures with slag exhibited similar heats of hydration. For the majority of mortar mixtures, the drying shrinkage was not significantly affected by PLC or OPC + LS in comparison to OPC; however, increases of 7–8% were seen for mortar mixtures including slag. At 7 days, some PLC and OPC + LS mortar systems demonstrated up to a 19.9 % reduction in flexural strength (M0: plain system [i.e., no SCM], M1, M2, which were the systems with fly ash), though a 5–7 % greater strength was noticed with slag. At later ages, the flexural strength difference between the PLC or OPC + LS and OPC mixtures was less pronounced (±5 % of each at 90 days) and was not statistically different.

FHWA 2023 – Produced in accordance with American Association of State Highway and Transportation Officials (AASHTO) M 240 or ASTM International (ASTM) C595, Portland limestone cement (PLC) is a binary blended cement. PLC is alternatively referred to as "IL," which denotes Portland cement-limestone blended cement and contains five to fifteen percent blended or inter-ground limestone. Because PLC has less clinker than ordinary Portland cement (OPC), it is designed to reduce global warming potential by 8.3 percent on average. Cement suppliers usually produce PLC with 10–12% limestone powder.

The industry is changing to produce more ASTM C595 cement, which means that PLC is becoming more widely available. In some markets, ASTM C150 OPC might no longer be offered as the shift proceeds. PLC has the potential to replace OPC in the United States, producing less than 8 million tons of CO2 emissions annually. This equates to removing more than 1.7 million cars from the road, based on the amount of OPC used in the country in 2021. PLC generally works well in place of OPC in concreting applications, requiring little modification to existing procedures and practices. Nonetheless, this guide can facilitate the switch from OPC to PLC and aid with any problems.

PLC exhibits comparable properties to its OPC in terms of compressive strength, flexural strength, elastic modulus, shrinkage, resistance to chloride ingress, resistance to alkali-silica reaction, resistance to scaling, and resistance to sulfate assault. PLC's increased fineness may cause some variations in fresh characteristics. PLC concretes in particular may show slower bleed rates, requiring additional time between placement and completion, as well as slight reductions in workability and setting times. PLC can be utilized with the same tools and processes that contractors presently employ. Because PLCs and SCMs work well together, PLC concretes can also be made using the SCMs that are already employed in OPC concrete.

Project F – Bridge Deterioration Modeling

Research Project Description

By analyzing existing deterioration models and incorporating Idaho-specific factors, this project seeks to provide a comprehensive and tailored approach to predicting bridge deterioration rates. The research will involve a systematic review of existing models, an in-depth analysis of Idaho's bridge infrastructure, and the creation of a customized deterioration model that considers variables such as climate, traffic patterns, and regional materials. The ultimate goal is to improve the predictive capabilities of deterioration models, enabling more effective maintenance planning and resource allocation for Idaho's diverse bridge network. The developed model will be incorporated into ITD's bridge management system, providing a practical tool for optimizing maintenance strategies and ensuring the longevity and safety of bridges in Idaho. The outcomes of this research will contribute valuable insights to the field of infrastructure management and aid ITD in making informed decisions.

Literature Review

The following literature review focuses on bridge and bridge element deterioration modeling research done in the previous 10 years. All modeling was done with a probabilistic approach with the exception of some projects producing both probabilistic and deterministic models.

North Carolina Department of Transportation (2015) – The University of North Carolina conducted research on bridge and culvert deterioration models, integrating them into the North Carolina Department of Transportation's (NCDOT) bridge management system (BMS). After addressing data anomalies within NCDOT's BMS, deterministic deterioration curves for bridges and culverts were generated. Subsequent findings revealed that probabilistic modeling, specifically employing a Markov-based approach, yielded more accurate predictions, and allowed for model confidence considerations. The traditional Markov-based model was adapted to accommodate the increase in condition state rating due to bridge maintenance and repair, as illustrated in Figure 2.36. Additionally, it was noted that these probabilistic models achieved high accuracy levels even without comprehensive consideration and implementation of external bridge deterioration factors.

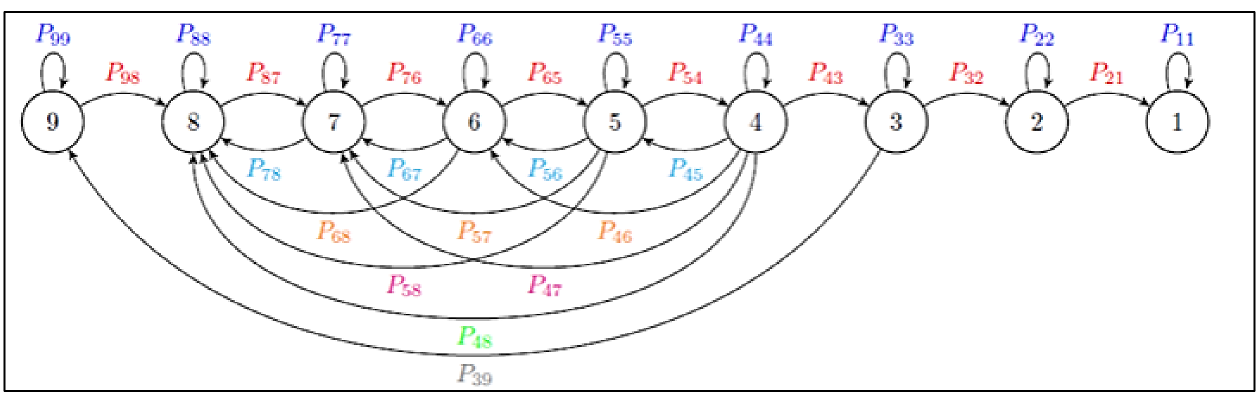


Figure 2.36 Suggested Modified Markov Chain Probabilistic Model (North Carolina DOT 2015).

In addition to developing deterioration models, UNC supported the integration of these models into NCDOT's BMS and facilitated ongoing updates with future data. The evaluation and revision of inputs used to calculate user costs in NCDOT's BMS included considerations for average daily traffic growth rates, vehicle operating costs, vehicle distribution, vehicle weight distribution, vehicle height distribution, accident injury severity, accident cost, and the algorithms used for bridge accident forecasting.

Michigan Department of Transportation 2016 – Kelley (Michigan DOT 2016) used a Markov-based deterioration model to study trends in bridge deterioration rates at five-year intervals for the Michigan Department of Transportation. The aim of this study was to determine the effectiveness of maintenance actions for deterioration rate of bridges. Since the National Bridge Element (NBE) data was only in its second year of data collection when this study started, only the National Bridge Inspection (NBI) Condition Rating data were used. The NBI data included deck, superstructure, and substructure ratings for bridges, and culvert rating for culverts. The rating changes in a given year were aggregated in five-year bands and the deterioration curves were determined for each period. The periods were 2000-2004, 2005-2009, and 2010-2014. Figure 2.37 shows the matrix used for deck ratings during the 2000-2004 period. The matrix was used to count bridges for every combination of new rating and old rating. The three colors of green, yellow, and red correspond to the bridges that improved at least one rating, remained the same, or deteriorated at least one rating, respectively. The green cells were ignored since condition rating improvement implies rehabilitation or replacement actions. In the case of deck rating, the matrix in Figure 2.37 shows the number of bridges in each cell for deck rating. For example, for old deck ratings of 6, a total of 25+14+137 = 176 bridges had an increase in rating, 6,245 bridges remained the same, and a total of 351+47+18 = 416 bridges had a decrease in rating.

2000-2004		New Deck Rating									
		9	8	7	6	5	4	3	2	1	0
Old Deck Rating	9	306	171	28	9	2	0	0	0	0	0
	8	15	1799	252	23	9	2	0	0	0	0
	7	6	31	4860	439	62	9	6	0	0	0
	6	25	14	137	6245	351	47	18	0	0	0
	5	51	40	36	213	2978	182	39	0	0	0
	4	58	42	10	25	70	1180	92	0	0	0
	3	60	40	7	13	27	43	875	5	0	0
	2	3	0	0	0	0	0	4	15	0	0
	1	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0

Figure 2.37 Deck rating changes in the years 2000, 2001, 2002, 2003, and 2004 (Michigan DOT 2016).

With the data in each matrix, the number of years to reach each condition rating was estimated. As an example, Figure 2.38 shows the deck deterioration trends for each of the three time periods and the composite curve. The results show that deterioration curves from 9 to 7 were virtually the same because few maintenance actions are necessary at high ratings. However, comparing the curves for ratings of 6 to 3, the curves show that the subsequent maintenance actions had a positive effect on deterioration over time for the 2005-2009 and 2010-2015 time periods.

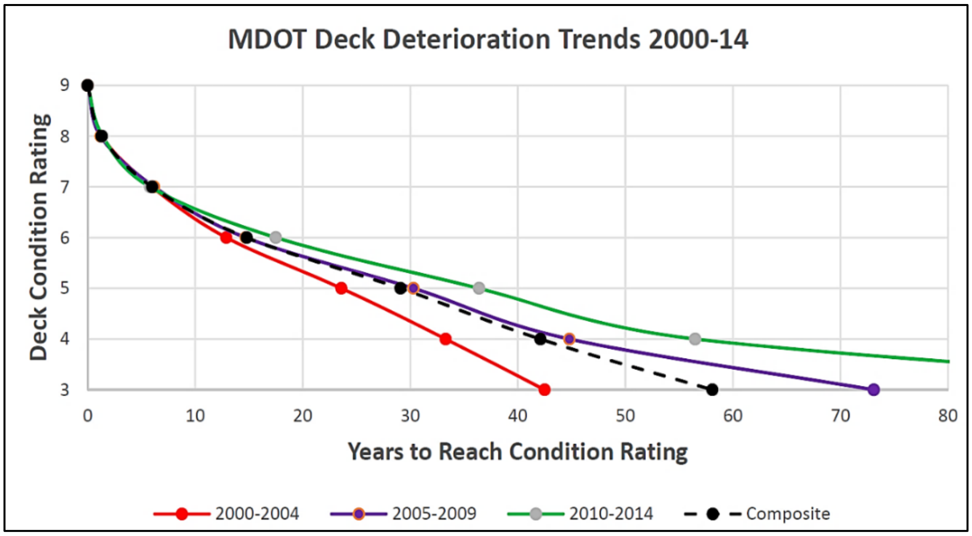


Figure 2.38 Deck deterioration trends 2000-14 (Michigan DOT 2016).

***Indiana Department of Transportation (2016)* –** A research project conducted at Purdue University developed curves representing deterioration models for bridge deck, superstructure, and substructure conditions. The bridges considered were located on the state highway system (Interstates, U.S. roads, and state roads). As a part of the study, a comprehensive literature review was done in which the following modeling techniques were investigated: (1) regression-based models, (2) Markov chain, (3) Poisson and negative binomial regression, (4) binary model, (5) Bayesian technique, and (6) Weibull-based probability density functions. Two models were developed in this study, one deterministic and the other probabilistic.

For the deterministic model a regression analysis was done. The NBI condition ratings for deck, superstructure, and substructure were used as the response (dependent) variables with the independent variables listed in the bottom of Table 2.33.

Table 2.33 Deterministic Model Variables.

Variable	
Response Variables	Deck Condition Rating Superstructure Condition Rating Substructure Condition Rating
Independent Variables	Component Age (years) Skew Type of Service Under Bridge Number of Spans in Main Unit Freeze Index (1,00's of degree-days) Interstate (1 if located on Interstate, 0 otherwise) Bridge Length

For the probabilistic model, a binary model was selected because the complexity associated with the estimation procedure could be simplified. The dependent variable is a 0/1 indicator variable for condition switching state. There were many more independent variables (21 in total) that were used in the probabilistic model. The independent variables included bridge age, district, component condition rating at last inspection year, average daily traffic, average daily truck traffic, average of cold days (<32°F) per year, average number of freeze-thaw cycles per year, bridge location on NHS route (0 or 1), etc.

The study found that environmental variables have significant effects on bridge deterioration. For several of the deterioration models, the climate variables of freeze index, number of freeze-thaw cycles, and average precipitation were found to be significant predictors of bridge component deterioration. In comparison with the superstructure and substructure, deck deterioration was found to be more affected by traffic loading.

Washington State Department of Transportation (2018) – O'Leary and Walsh (Washington State DOT 2018) completed a research project at Saint Martin's University to determine deterioration of concrete pile/column elements. Both dry concrete pile/column elements (Element ID 205) and submerged concrete pile/column elements (Element ID 227) were considered. The state of Washington was divided into Eastern and Western regions using the Cascade Mountain Range as a dividing line. These two regions have distinct climates with the Eastern region having hot dry summers and winters with many more freeze/thaw cycles. The Western region does not have as many freeze/thaw cycles, but experiences large amounts of rain including harsh coastal areas. Each larger region was composed of three smaller sub-regions, giving a total of six sub-regions. Initial analyses were done for data within each of the six regions and then combined into Eastern and Western regions.

Washington State DOT utilizes a grading scale of 1-4 for Condition States of Structural Members. These Condition States represent Good, Repaired, Fair, and Poor Conditions, respectively. Figure 2.39 shows two examples of Fair and Poor conditions (Washington State Bridge Inspection Manual 2023).

(a) (b)

Figure 2.39 Examples of (a) CS3, Fair Condition, and (b) CS4, Poor Condition (Washington State DOT 2018).

Initial analyses were done on the relationship between bridge age and condition states, and the average number of years an element stayed in a given condition state. Then probabilities were developed for transitions from an initial state to a lower state, assuming that an element can only transition by one state. For example, it is only possible to go from CS1 to CS2, not from CS1 to CS3 or from CS1 to CS4. Two of the four transition probability matrices for Eastern Washington are shown in Figure 2.40. Similar matrices were developed for Western Washington.

I. *Eastern, WA Element ID 205*

	CS1	CS2	CS3	CS4
CS1	0.652	0.348	0	0
CS2	0	0.357	0.643	0
CS3	0	0	0.991	0.009
CS4	0	0	0	1

III. *Eastern, WA Element ID 227*

	CS1	CS2	CS3	CS4
CS1	0.758	0.242	0	0
CS2	0	0.303	0.697	0
CS3	0	0	0.939	0.061
CS4	0	0	0	1

Figure 2.40 Transition Probability Matrix for Element 205 and 227 for Eastern Washington (Washington State DOT 2018).

The study concluded that there is no significant difference in deterioration rates between bridges in Eastern and Western Washington. In addition, there is a higher percentage of transition for dry elements transitioning from CS1 to CS2. However, transitions from CS2 to CS3 and CS3 to CS4 are higher for submerged elements.

Texas Department of Transportation (2020) – The University of Texas at San Antonio completed the development of bridge and culvert deterioration models for the Texas Department of Transportation (TxDOT). This research was unique to other bridge deterioration modeling research because it utilizes Markov-based modeling that allows for a condition state transition of more than 1 for a single bridge inspection cycle of 2 years. A Markov-based model is time independent in the sense that the probability that a transition from one condition state to another occurs independent of past states. In addition, Markov-based modeling uses a transition probability matrix that represents the probability a bridge component would transition from one condition state to any lower condition states during a specified time. During the process of creating the bridge deterioration model, researchers found the following variables to have relevant bridge deterioration impacts and included them within the model: (1) rainfall, (2) deicing effects, (3) truck traffic type, (4) component age, and (5) component type. An example of a deterioration model prediction can be seen in Figure 2.41.

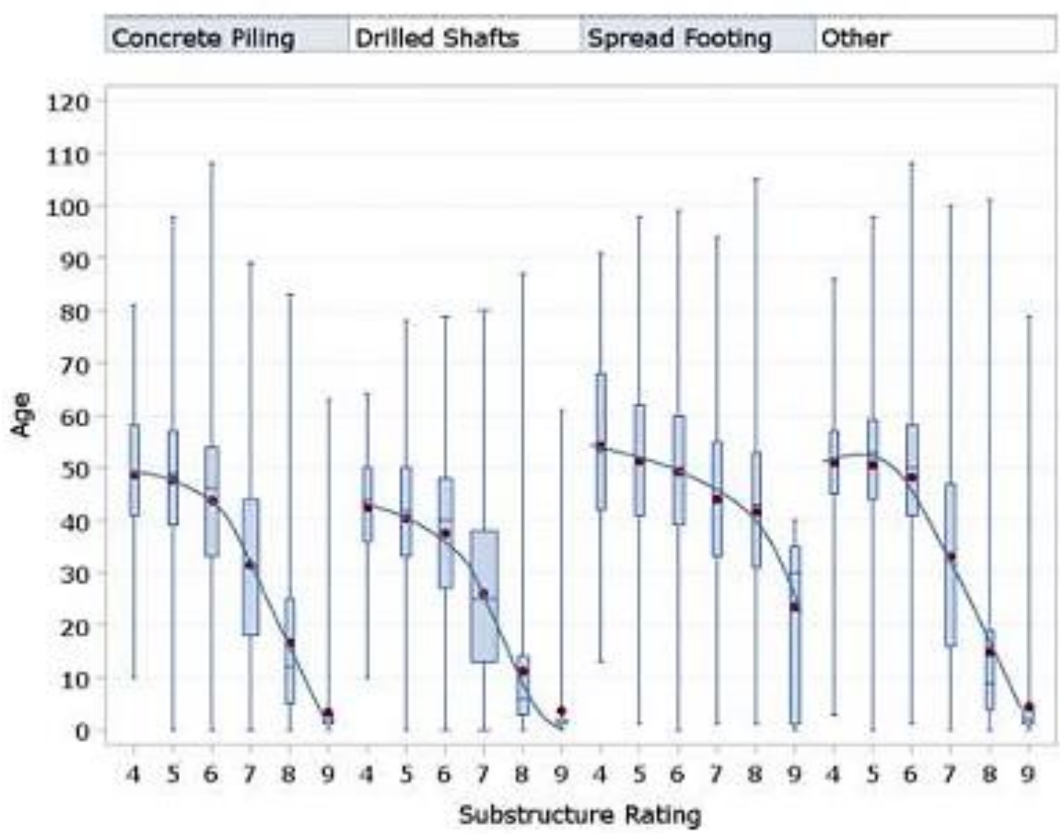


Figure 2.41 Example of Age Boxplots by Potential Substructure Modeling Family (Texas DOT 2020).

The developed bridge deterioration model has a notable limitation in how the program analyzes condition state transitions. During execution, the program disregards data where the condition state transition increases, assuming it indicates maintenance or repairs. However, the program cannot distinguish if maintenance was performed to maintain a condition state rating. Consequently, it assumes no maintenance was done, leading to less conservative predictions. The exact frequency of such situations during data processing is unknown, but a rigorous validation process suggested that the variance from this circumstance was negligible.

Illinois Department of Transportation (2021) – The Illinois Department of Transportation (IDOT) employs deterministic bridge deterioration modeling. To assess this model, biennial condition rating (CR) bridge data from 1980 to 2020 was sourced from the National Bridge Inventory (NBI) to evaluate its accuracy. The findings revealed that the model consistently overestimates maintenance, repair, and rehabilitation costs for all bridge components, except for deck beams, which are consistently underestimated. An example of the validation process is shown in Figure 2.42, where the current IDOT model is orange, the historical data is in black, and a prediction from Indiana's bridge deterioration model is blue. The current model for Illinois can be seen grossly underestimating the deterioration rate of all bridge substructures in region 5.

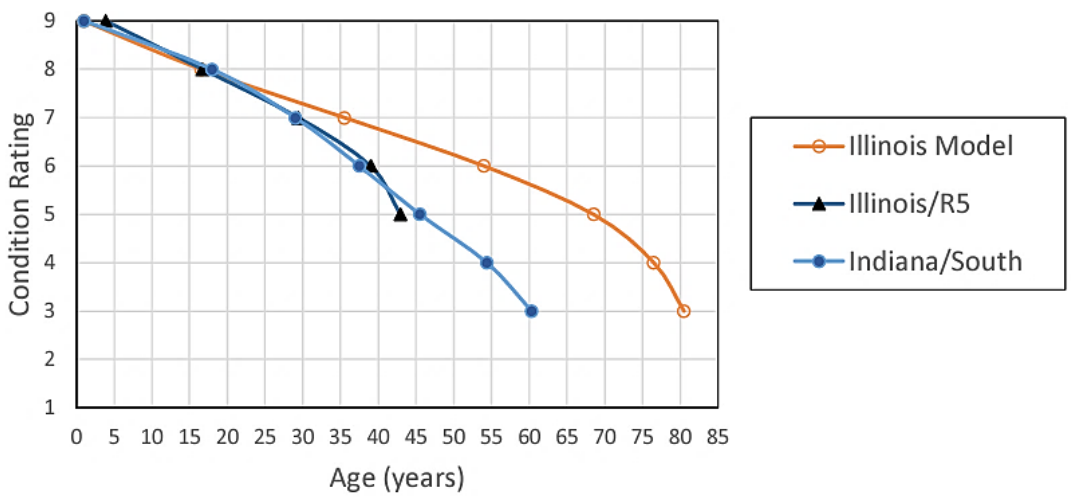


Figure 2.42 Illinois Region 5 vs Indiana South: Substructure (Illinois DOT 2021).

To resolve these inaccuracies, two tasks were conducted: (1) a multistate survey assessed methodologies used, determining whether models were state- or region-based, and (2) a thorough literature review identified a modeling approach aligning with IDOT needs. These tasks led to key observations and suggestions for the development of a future deterioration model:

- A probabilistic model is recommended.
- Almost every transition time between two CR levels produced significant variations.
- NBI data of region 1 in Illinois provided small standard deviations, resulting in reduced uncertainty in probabilistic models.

- Data for low CR levels was lacking since low CR levels are usually quickly repaired. In these scenarios, using the standard deviation of higher CR levels proved adequate.
- The Weibull distribution modeling approach proved to be viable.
- Other variables, such as truck traffic intensity, structure component features, and environmental factors, should be considered.

Montana Department of Transportation (2022) – Montana State University undertook a project utilizing data from the National Bridge Inventory (NBI) to develop deterioration curves for bridge elements. These deterioration curves, based on a Weibull distribution, were designed to interface with the Montana Department of Transportation's (MDT) bridge management software (BMS), AASHTOWare (BrM).

The completion of this project involved (1) a comprehensive literature review to establish best practices, (2) collecting data from the NBI and MDT's BMS, (3) determining region-specific deterioration curves for steel girders, concrete abutments, steel culverts, reinforced concrete decks, prestressed concrete girders, and concrete culverts across Montana's five maintenance districts, (4) validating and revising the element-based deterioration curves based on historical bridge data and MDT's experience, and (5) investigating differences in deterioration rates among Montana's five districts. A more detailed delineation of these tasks are as follows:

1. Comprehensive Literature Review:
    - Reviewing both deterministic and stochastic modeling techniques.
    - Developing an understanding of physical and machine learning models.
    - Analyzing deterioration curves from state DOTs, including Nebraska, Wyoming, Wisconsin, Indiana, New York, California, and Texas.
2. Data Collection:
    - Collecting data from both the FHWA's NBI and MDT's BMS.
3. Determination of Region-specific Deterioration Curves:
    - Evaluating statistical methods, such as a Weibull distribution, to capture prediction uncertainties.
    - Investigating and determining deterioration rate parameters.
    - Creating and graphing region-based deterioration curves.
4. Validation and Revision of Mathematical Model:
    - Performing validation tests based on deterioration targets.

- o Revising deterioration curves by adjusting environmental factors and input parameters.

5. Investigating Deterioration Rate Dissimilarities Among Districts:
   - o Exploring region-based environmental factors.

An example of the graphs mentioned in task three can be seen in Figure 2.43. The smaller graph in the upper right corner shows the percentage of total deck area within condition state 1 over time of the newly developed model (dotted) superimposed with the default BrM model (solid line).

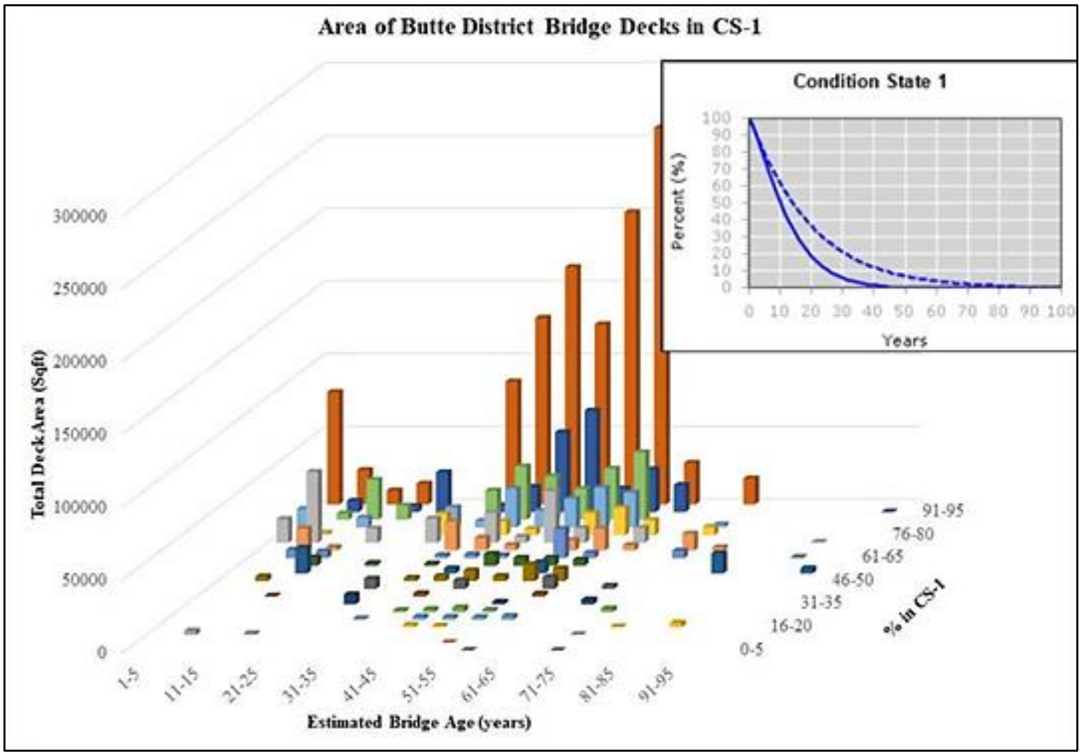


Figure 2.43 Butte District Bridge Decks in Condition State (CS) 1 (Montana DOT 2022).

Missouri Department of Transportation (2022) **–** Sponsored by the Missouri Department of Transportation (MoDOT), the Missouri Center for Transportation Innovation (MCTI) conducted a research project analyzing National Bridge Inventory (NBI) data specific to Missouri from 1983 through 2019. The aim was to predict the deterioration of state bridges and culverts exploring specific parameters that were believed to accelerate bridge deterioration and offer recommendations for cost effective designs.

Two deterioration models were developed: one employed a Kaplan-Meir survival methodology to estimate the duration a bridge or culvert may remain in a specific condition state rating, while the other utilized Cox regression to identify the factors most influential in bridge or culvert deterioration. Key factors considered in the analysis encompassed the rate of salt application, span length, traffic volume, cast-in-place bridge deck utilization, and environmental conditions. Figure 2.44 illustrates an example of a deterioration model using the Kaplan-Meir survival methodology, depicting the service life of various superstructure types.

The study's findings indicate that, (1) in most cases, deicing salt application exhibited twice the impact compared to other factors, (2) increased bridge span length was associated with higher deterioration rates, (3) average daily traffic and average daily truck traffic showed no significant effect on deterioration rates, (4) deterioration rates were significantly influenced by geographical regions, and (5) deterioration rates increase at condition state ratings of 5 and below.

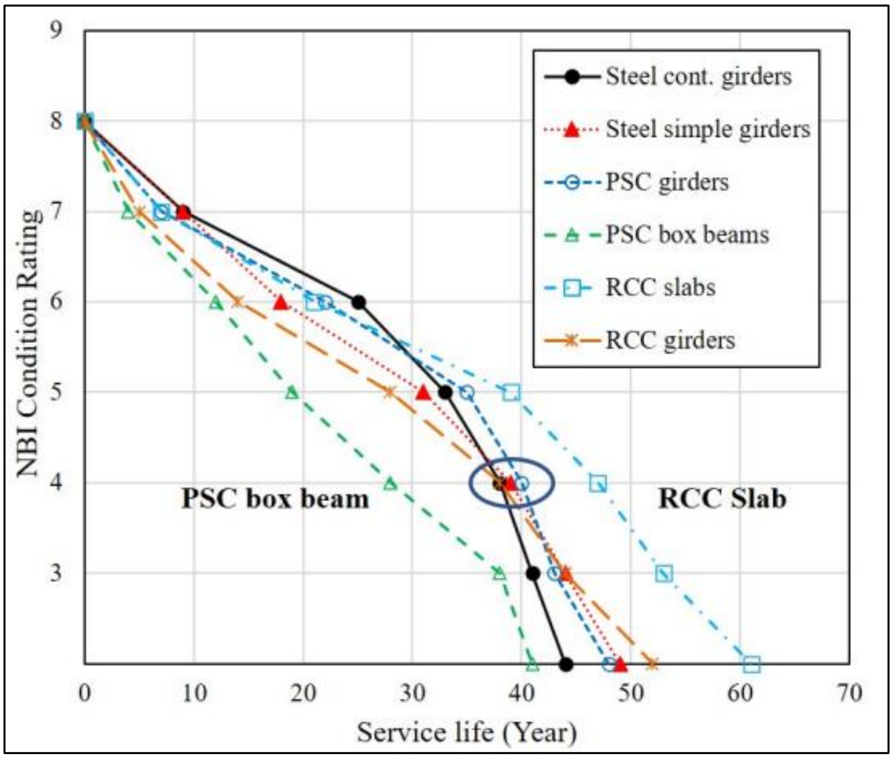


Figure 2.44 Service Life Plot for Different Types of Superstructures (Missouri DOT 2022).

3. Project Request Forms for Selected Projects

Project A – Evaluation of ITD's Bridge Deck Preservation Strategies

TITLE:

Evaluation of ITD's Bridge Deck Preservation Strategies

SUBJECT AREA:

(e.g., Pavements, Bridges, Environment, Maintenance, Safety, Planning, Management, etc.)

Bridges

PROBLEM STATEMENT:

What problem would be addressed by this project?

The project aims to determine if the current ITD's bridge deck preservation strategy is optimum for preserving bridge decks in Idaho. In addition, are there alternate materials for new bridge decks in ABC applications that is comparable in strength to Polyester Polymer Concrete (PPC) overlay with lower cost and shorter construction time?

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.

A preliminary literature review is conducted on the current state of practice in the areas of bridge deck overlay materials, construction, and rehabilitation strategies to extend the service life of concrete bridge decks. In particular, the research reports and other documents that have been published in the last 10 years are considered.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

1) Review ITD's current bridge deck preservation strategies.

2) Perform a comprehensive literature review to identify best practices in bridge deck overlay applications.
3) In consultation with ITD bridge and materials engineers, optimize the bridge deck overlay process for new and existing bridges.

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

1) Review ITD's current bridge deck preservation strategies for existing bridges.
2) Examine current ITD practices in applying new bridge deck overlays, including those related to ABC.
3) Perform a comprehensive literature review for best practices in bridge deck overlays.
4) Perform independent laboratory tests on small panels representing the bridge deck with various overlay materials, including new materials on the market. In addition, prepare small test cylinders using the overlay materials. Subject the panels and small specimens to freeze-thaw cycles. Before and after freeze-thaw cycles, perform (a) standard ASTM tests on the test cylinders, and (b) flexural tests on the panel specimens to examine the bond between the overlay and substrate concrete. In addition, perform other validation testing. Summarize the test results.
5) In consultation with ITD Technical Advisory Committee (TAC), suggest guidelines for different deck preservation strategies which are dependent on various factors (e.g., average daily traffic, climate, structure type) with options for cost vs. service life.

What deliverables/outputs will be produced?

1) A thorough overview of the current state of practice in bridge deck preservation.
2) Laboratory test results.
3) Guidelines for bridge deck preservation.
4) A comprehensive final report.

How will the research results be implemented?

It is recommended to incorporate the bridge deck preservation process into relevant ITD manuals.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

1) Reduce costs and construction time for ITD bridge deck preservation efforts.
2) Provide better bridge deck surfaces for public use.

3) Increase safety, since the goal is to extend the deck service life and reduce the number of times the bridge will see construction related to overlays or deck replacement.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

1) Safety: Extending the service life of bridge decks reduces the risk of structural failures and construction intervention.
2) Mobility/Economy: A bridge with a well-preserved bridge deck is more likely to maintain its original load-carrying capacity with less required maintenance. This extends operational lifespans and allows for an increased utilization of bridges by cargo trucks.
3) Innovation: A new preservation process for bridge decks can be applied to other infrastructure projects, facilitating progress in construction technologies.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

The proposed work is expected to yield several practical benefits, including:

1) Cost Savings:
   Measurement - Quantify the reduction in maintenance costs and emergency repairs over time.

2) Process Efficiencies:
   Measurement - Assess the time and resources saved through optimized preservation processes. Evaluate the efficiency gains in inspections, maintenance interventions, and overall bridge management.

3) Accident Reduction:
   Measurement - Track accident occurrences related to bridge deck conditions before and after implementing the proposed preservation measures. Analyze accident reports and trends to assess the impact on safety.

4) Extended Service Life:
   Measurement - Evaluate the increase in the average service life of bridge decks compared to historical data.

5) Resource Optimization:
   Measurement - Quantify the optimization of resources, including materials, labor, and equipment. Compare resource utilization before and after the proposed changes.

6) Public Perception and Satisfaction:
   Measurement - Conduct surveys or other public feedback mechanisms to gauge the community's perception of the bridge conditions and overall satisfaction with the reduced construction disruptions.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid.

Is there a well-supported reason the project can/should not be competitively bid?

______ *Yes*
__**X**__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: ____24________ **months**
Estimated Cost for the Project: $____170,000____

Project B – Implementation of Internal Concrete Curing to Enhance Concrete Performance

TITLE:

Implementation of Internal Concrete Curing to Enhance Concrete Performance

SUBJECT AREA:

Pavements, Bridges, Environment, Maintenance, and Safety

PROBLEM STATEMENT:

What problem would be addressed by this project?

Premature cracking of bridge decks has been a problem for several DOTs in the last decade. Most of the cracking in Idaho is due to drying shrinkage or Alkali-Silica Reactivity (ASR). Most DOTs have used various concrete mixtures, types (high performance concrete), and admixtures to prevent it and to control such cracking. Once concrete cracking starts in concrete pavement and bridge elements, the cracks get wider under service loads and due to harsh environment. The wider cracks reduce the serviceability and service life of roads and concrete bridge members, consequently, increases maintenance and replacement costs. Most of the DOTs currently use high performance concrete in their mixtures for high compressive strength and durability, however, the high cement content and the low water-to-cement ratio likely contribute to the drying shrinkage. The Idaho Transportation Department (ITD) has employed mitigating approaches such as crack sealing and thin polymer overlays to address early-age deck cracking due to drying shrinkage; however, these strategies are costly and have impacts on traffic operations due to the need for repeated applications through the life of the pavement and structures. Admixtures and secondary cementitious materials (SCMs) are often used in the concrete mix to mitigate for ASR; however, these constituents can be very costly and do not always mitigate as intended.

How is ITD impacted by the problem?

The reduced service life and serviceability are directly related to increased replacement costs. Although concrete components are designed to last 50 to 100 years, some elements have had to be replaced within 10 years. With limited funding, these unanticipated replacement costs are taking funds from other important projects. It is difficult to maintain a transportation improvement plan when designs are not lasting their anticipated life.

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, *explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.*

A preliminary literature review will be conducted on the current state of practice in the areas of internal concrete curing to extend the service life of concrete bridge members. In particular, the research reports and other documents that have been published in the last 10 years are considered.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

Internal curing of concrete structures has been used in various states such as Illinois and Wisconsin as a robust strategy to control concrete cracking during service life. Western Federal Lands has used it on at least two projects in Idaho. Enhanced Performance through Internal Concrete Curing (ICC) is currently one of the FHWA's Everyday Counts initiatives. Internal curing provides a source of moisture from inside the concrete mixture, improving its resistance to cracking and overall durability (Source: FHWA).

The most widely used approach for ICC uses presoaked lightweight aggregates as a partial replacement to the fine aggregate to provide curing water during the hydration process for more complete curing of the concrete, which reduces drying shrinkage and cracking. This curing water is not counted in the water to cement ratio because the water from the lightweight aggregate is used by the concrete once the concrete has hardened.

ICC has also been reported to mitigate for ASR, however, this theory has not been tested with the reactive aggregates in Idaho.

Performance measures would be identified and used to measure success.

This project's main goal is to successfully implement ICC technology at the Idaho Transportation Department through, a) identify appropriate products and materials (aggregates) and prewetting techniques for the implementation of ICC in ITD concrete mixtures; b) Develop ICC specifications that include mix design parameters that allow for the utilization of "locally" available ICC products; c) Identify quality control and quality assurance specifications for ICC; d) Identify performance measures to verify the successful use of ICC; d) Investigate the effect of ICC on mitigating the ASR of ITD concrete mixtures.

Specifically, the following questions need to be addressed:

1) What products provide the most effective method for ICC in concrete bridge decks (e.g., pre-wetted expanded lightweight aggregate, recycled concrete aggregates, superabsorbent polymers, or cellulose fibers)?

2) Are the products evaluated in “a” locally available for use in ITD projects? In this case, locally is defined as geographically available for delivery to batch facilities for ITD projects with the benefits outweighing the costs of transport. Benefits should include lower life cycle costs by increasing the service life of bridge decks.
3) What Quality Control and Quality Assurance requirements are necessary for successful implementation of ICC technology at ITD.
4) Can we quantify the effects of internal concrete curing on the material properties of the hardened concrete (strength, permeability, freeze and thaw etc.) compared to some previously used mix designs?
5) What are the lifecycle cost savings associated with using internal curing for bridge decks?

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

Task 1. Literature Review of Current Uses, Practices, and Specifications (survey of practice). Summarize information available related to current practices at various other state DOTs, industries, and manufacturers. Include what was successful and what was not successful, and why it was deemed as such. Determine which products are being used successfully.

Task 2. Research the availability and cost-effectiveness of the products that have been used successfully.

This will involve some research into where these products can be obtained, the cost of purchasing the products for an example project and the cost of shipping these products to the various districts in Idaho, using each District Headquarters as a base point for location. The example project will be a fictional project that includes a concrete bridge deck and concrete paving as a means to compare costs of standard concrete mixes with internally cured concrete mixes being delivered to each of the districts.

Task 3. Intermediate report summarizing Tasks 1 and 2.

An intermediate deliverable will be a report summarizing the data collected in Tasks 1 and 2. From this report, ITD will select 3 to 5 products for evaluation in the next phases.

Task 4. Compare hardened concrete properties and ASR properties to previously used mix designs. (Extensive laboratory testing)

Cores can be collected from existing bridge decks and concrete pavements that we know have experienced significant cracking from either shrinkage or ASR. Petrography can be used to analyze the reasons for failure. Research can be done on the mix designs that were used and the test results of the hardened properties at the time of placement. Using the products selected in Task

3, these mix designs would then be adjusted to use the products available for internally cured concrete, and comparisons would be made with the previous test results.

One thing that would have to be considered is that Type I/II cement is no longer available. The previous mix designs likely had Type I/II cement. The industry has moved to Type IL. This could provide different results regardless of the ICC products used, but the results would not be expected to be significant. Mix designs without the ICC products may have to be tested as well to establish a baseline for comparison.

Place small (8' x 8') temporary slabs using each mix design under normal placement conditions. ITD might be able to provide a source that has available space to store these slabs until they are no longer needed. These slabs could be cored if needed for petrographic analysis.

Design and conduct laboratory investigation that would provide insight to the performance of internal cured concrete as a crack control mechanism. These laboratory tests and experiments would be focused on the properties of shrinkage, moisture loss, strength and other key parameters that reflect the overall effectiveness in controlling cracking in bridge decks and concrete pavement.

Laboratory experiments should be designed and conducted unique to bridge decks and to concrete pavements. These experiments are used to quantify the material benefits of using internal curing and to develop information needed to adjust parameters used in ITD bridge concrete mixes and testing as well as concrete pavement mixes for inclusion of internal curing.

Task 5. Estimate Life Cycle Costs

Based on the cost analysis in Task 1, and the petrographic analysis and testing performed in Task 2, estimate the life cycle costs of each mix design evaluated. Quantify the estimated impact the internally cured concrete has on the life cycle costs compared to the standard mix concrete.

Task 6. Specifications, Quality Control, and Quality Assurance.

Assuming the results from Task 3 show a significant life-cycle cost benefit using internally cured concrete, based on the research in Tasks 1 through 5, develop mix design parameters and specifications that can be used for internally cured concrete. Along with the mix design specifications, develop quality control and quality assurance specifications to ensure a consistent quality product.

Task 7. Pilot Projects

ITD will select three representative bridge decks that are suitable for ICC. One of these bridges will use conventional concrete mix and the other two will adjust the conventional concrete mix for internally cured concrete mixes. ITD will inform the Association of General Contractors of Idaho that a pilot project for internally cured concrete is eminent. Using the specifications developed in Task 6, ITD will include these specifications in the advertisement(s) for these bridges.

Internal curing mix performance will be tested with an emphasis on comparing mechanical, freeze-thaw, shrinkage, fresh, ASR, and transport properties.

Task 8. Recommendations and Specifications Development

What deliverables/outputs will be produced?

An intermediate, and draft and final report in the ITD format will be the primary deliverables for this project, (1) incorporating the intermediate report from Task 3 summarizing the results from Tasks 1, Literature Review and 2, Availability and Cost-Effectiveness of Products; (2) Comparing hardened concrete properties and ASR properties to previously used mix designs; (3) Quantifying the benefits of ICC using life-cycle cost analysis; (4) internal curing specifications that specify mix design parameters and quality control/ quality assurance requirements for successful implementation of ICC at ITD; (5) data from laboratory and field tests (if applicable); (6) Modify the specifications developed for the pilot projects based on lessons learned,; (7) conclusions and recommendations for future work. Among the deliverables is a presentation to ITD that summarizes the study's results.

A PowerPoint presentation will be provided to ITD for ITD Bridge Maintenance, Bridge Asset Management, Pavement Maintenance, and Regional Planning personnel to use as a training aid.

How will the research results be implemented?

Assuming that the research results indicate an overall benefit to the taxpayer in reduced life-cycle costs and reduced maintenance costs, ITD will incorporate the specifications developed with the research into the ITD manuals for inclusion in future projects. ITD will reach out to their own staff, as well as the contracting and consultant communities to discuss the finding and the benefits of using internally cured concrete.

Additional research might be needed on concrete pavements and other concretes used in ITD construction.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

It is anticipated that the internal curing process will provide a better concrete product which will increase the durability of the concrete, reduce maintenance costs, and lengthen its service life. This happens specifically because internal curing allows for a more complete and efficient hydration of the concrete. This reduces the likelihood of shrinkage and thermal cracking and provides a less permeable concrete that resists moisture and chloride penetration that tends to reduce the service life of the bridge deck or concrete pavements.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

Using conventional concrete for bridge decks and concrete pavements has resulted in concrete cracks due to thermal cracking and shrinkage, as well as from alkali-silica reactivity. This requires ITD to take additional measures (e.g., polyester concrete overlay) to protect the concrete, which adds significant costs.

Using internally cured concrete (ICC), it is anticipated that the additional measures to protect the concrete will no longer be necessary, or at least not as extensive as they are now. This results in cost savings which translate to more money being available for other important projects. This improves the mobility, economic opportunity and safety to the traveling public.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

Longer service life will result in lower equivalent uniform annual maintenance costs for concrete. An economically and structurally sound option for ITD will be made possible using internally cured concrete. The project's outcomes will enable ITD to concentrate on maximizing return on investment, minimizing early-age cracking and traffic flow disruptions, effectively reducing life cycle cost, and optimizing the value of bridge materials and performance.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid

Is there a well-supported reason the project can/should not be competitively bid?

_____ *Yes*
__X__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: **24 months**
Estimated Cost for the Project: **$200,000**

Project C – Develop Reliable Camber Prediction Equations for Deck Bulb-T Prestressed Girders

TITLE:

Develop Reliable Camber Prediction Equations for Deck Bulb-T Prestressed Girders

SUBJECT AREA:

(e.g., Pavements, Bridges, Environment, Maintenance, Safety, Planning, Management, etc.)

Bridges

PROBLEM STATEMENT:

What problem would be addressed by this project?

Prestressed Deck Bulb-T girders have a highly complex camber maturity curve due to their sensitivity to various fabrication procedures including mix design, bed configuration, concrete dimensional tolerances, curing operations, prestressing pressures and moisture control tolerances, storage environment, and support location during storage. The type of aggregates, cement, and admixtures used in the concrete also affects concrete creep and shrinkage, which significantly impacts long-term camber. For prestressed concrete girders, ITD currently uses empirical formulae based on multipliers to calculate instantaneous and long-term camber. The current empirical camber prediction models may not be effective for the recent concrete mixtures with new cement and admixtures formulations (e.g., type IL cement). As a result, there is a need to reconsider the ITD processes currently in use for predicting camber for Deck Bulb-T girders. Revisions to processes should consider current fabrication techniques and be supported by actual values for camber measured during ITD bridge construction projects.

Correct camber predication is more critical for Deck Bulb-T girders, where mitigations for camber variations is more limited and difficult in the field. In contrast, camber variations in standard Bulb-T and AASHTO type girders with cast-in-place deck can be more readily mitigated in the field by variable camber strip thickness. Therefore, this research should be particularly focused on Deck Bulb-T girders, but also may include girders with cast-in-place deck. Therefore, improved camber prediction equations for standard Deck Bulb-T girders should be developed by systematically identifying the most important parameters, practices, and predictive analytical models.

How is ITD impacted by the problem?

It has been noted that the current camber prediction system for prestressed concrete Deck Bulb-T girders underestimates or overestimates the long-term camber of some of Deck Bulb-T girders. The timing of bridge construction has a significant impact on long-term camber prediction, and it typically leads to an overestimation or underestimation of the long-term camber for Deck Bulb-T girders. Moreover, it has been discovered that Deck Bulb-T girders, having the same length and the same material cast on the same bed, might have different cambers. Construction costs have gone up because of this inconsistency and the inability to estimate the long-term camber accurately, raising questions about quality control. The intent of Accelerated Bridge Construction (ABC) is to expedite construction and improve quality control, typically coming with a higher construction cost while saving associated production costs (e.g., public detour impact costs). Overestimating and underestimating girder camber usually results in unintended additional work due to placement of thicker polyester polymer concrete (PPC) or other overlay material for Deck Bulb-T girders. In extreme cases, deck profile grinding may be required for Deck Bulb-T girders when counter-camber (i.e., deck thickening) is built into the girder. Underestimating the camber for conventional prestressed girders with a cast-in-place deck typically involves adjusting the design height of the camber strips (or haunches) but may also lead to added concrete and wearing surface in extreme cases.

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.

A preliminary literature review was conducted on the current state of practice for the development of more reliable camber prediction for prestressed Deck Bulb-T girders.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

The aim of this study is to reduce the discrepancy between the expected and actual camber of Deck Bulb-T girders, particularly during the time of construction, and to enhance both the short- and long-term camber prediction equations/models. The project's objectives will be achieved by methodically analyzing the material behavior throughout the short- and long-terms, looking into camber measurement methods, and measuring camber from the point of Deck Bulb-T girders construction at the precast plants until the complete erection of those girders in bridges. In addition, the staged bridge construction might also affect the prediction of camber values and it might be factored into the potential prediction equations.

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

The project objectives:

1) Complete a thorough literature review with an emphasis on recently completed work on this research topic.
2) Review the existing camber data recorded in the past by pre-casters at transfer and by contractors and the Idaho Transportation Department at the time of erection.
3) Quantify concrete properties such as compressive strength, modulus of elasticity, creep, and shrinkage for representative concrete mixes from three pre-casting plants, considering the new cement types such as Cement IL.
4) Obtain accurate camber measurements from a variety of Idaho Transportation Department deck Bulb-T girders at the time of transfer, during storage at the precast plants, at the time of erection, and before/after the casting of the deck.
5) Investigate the potential sources of scatter in the measured data for both the instantaneous camber and the long-term camber and quantify the effects of different variables such as concrete material properties, camber measurement techniques, bed deflection, creep and shrinkage, support location (i.e., overhang length), thermal effects, human error, and repeatable measurement processes.
6) Propose a new measurement approach to accurately capture the instantaneous camber and recommend any modifications to the Deck Bulb-T girders fabrication process to decrease variations in the camber of identical Deck Bulb-T girders.
7) Improve the estimation of the instantaneous camber in conjunction with the measured field data, develop analytical models using finite element analysis (FEA) and simplified analysis to compute a new set of long-term camber multipliers to predict the at-erection camber more accurately. Note that this may or may not require providing separate multipliers for each manufacturer or setting limits on the ratio between the at-release (f'_{ci}) and 28-day (f'_c) concrete compressive strengths.

What deliverables/outputs will be produced?

1) A thorough overview of the current state of practice in development of more reliable camber prediction for prestressed Deck Bulb-T girders.
2) Field data, pre-casters input, and laboratory (if any) results of camber prediction equations/models.
3) Guidelines and implementation plan for ITD bridge section including equations and multipliers as appropriate.
4) A comprehensive final report.

How will the research results be implemented?

It is recommended to include the camber prediction models in the ITD bridge design guidelines.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

The deformation of concrete bridge superstructure elements constructed in a sequential manner is highly influenced by the time dependent behavior of concrete (ability to creep and shrink over time). Delayed deformations compared to those predicted during design may affect the serviceability of concrete bridges or may result in increased cost and longer construction duration. A procedure to predict each stage of camber in Deck Bulb-T girders from beginning to the end of service life, will help ITD overcome current construction problems resulting from the inaccurate camber prediction models.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

In recent years, there has been a greater emphasis on the ride quality of bridges in Idaho. The two main parameters influencing this ride quality are the deflection of the bridge girders and girders' camber. In addition to required modifications during construction, actual camber values that differ from those designed values may also raise costs and lengthen the construction time of the project. If the designated deck surface elevations are not attained, the deck may need to be ground in order to ensure that the final deck surface closely resembles the vertical roadway geometry. Therefore, the overall benefits to ITD will be significant saving of money and time.

- Material and Labor Costs: More reliable camber prediction models will help in shortening bridge construction time, which will reduce the labor cost.
- Reduced Maintenance Costs: The enhancement of camber prediction models will result in a better transition between roadways and bridges, which will improve the ride quality and therefore reduced the maintenance cost over the life cycle of a structure.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

This study's ultimate goal is a comprehensive framework that can be used to predict ITD Deck Bulb-T girder camber at any point in the bridge's service life. Providing better camber estimations for new bridge projects, will provide better ride quality, and fewer field modifications are further advantages. This research will affect drivers as well as ITD bridge designers, construction workers, and consultants.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of

research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid.

Is there a well-supported reason the project can/should not be competitively bid?

______ *Yes*
__**X**__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: ____36________ **months**
Estimated Cost for the Project: **$____350,000____**

Project D – Use of Non-Proprietary UHPC in Idaho Bridges

TITLE:

Use of Non-Proprietary Ultra-High Performance Concrete (UHPC) in Idaho Bridges

SUBJECT AREA:

(e.g., Pavements, Bridges, Environment, Maintenance, Safety, Planning, Management, etc.)

Bridges

PROBLEM STATEMENT:

What problem would be addressed by this project?

The successful completion of this project would enhance the durability and extend the lifespan of various critical bridge components, including bridge deck field cast connections, seismic retrofitting, and element repairs. This advancement is expected to result in reduced maintenance frequency, leading to cost savings and, more importantly, improved public safety by utilizing materials with superior performance.

How is ITD impacted by the problem?

The aging infrastructure of bridges has driven ITD to allocate significant resources to the rehabilitation and reconstruction of these structures. Consequently, this results in an increased frequency of maintenance inquiries and longer bridge traffic downtime for the public.

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.

A preliminary literature review was conducted on the current state of practice on development and use of non-proprietary UHPC for bridge applications. In particular, the research documents that have been published in the last 10 years are considered.

While various instances of non-proprietary UHPC development have been researched, this project specifically focuses on utilizing constituents sourced within Idaho to reduce material costs.

Additionally, the project aims to establish implementation guidelines tailored to this newly developed UHPC, considering Idaho-specific impacts, such as climate.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

This project endeavors to develop an optimum non-proprietary UHPC and facilitate its application in Idaho bridge construction and rehabilitation. Applying this non-proprietary UHPC alongside the resulting implementation guidelines will reduce the cost of bridge construction and rehabilitation. This approach ensures an increase in infrastructure resilience and lower costs while maintaining traditional UHPC performance.

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

1) Review ITD's current use of UHPC in bridges.
2) Perform a comprehensive literature review on (a) development of non-proprietary UHPC by various researchers throughout the U.S. and in other countries, and (b) use of non-proprietary UHPC in bridge applications.
3) Develop an optimum non-proprietary UHPC mix that uses readily available materials in Idaho and domestic products (e.g., steel fibers).
4) Perform standard laboratory tests on the optimum UHPC mix that include fresh mix flow test, compression and tensile strength, bond strength, and shrinkage. Summarize the test results.
5) In consultation with ITD Technical Advisory Committee (TAC), select an application for the developed non-proprietary UHPC in a new bridge. For example, this material could be used in closure pours connecting deck bulb-T girders.
6) Work closely with TAC members and selected material suppliers and contractors to develop an effective means of UHPC implementation.
7) Monitor the performance of the UHPC over a period of time after construction.
8) Establish implementation guidelines for UHPC use in selected bridge applications.

What deliverables/outputs will be produced?

1) A thorough overview of the current state of practice in non-proprietary UHPC with focus on the use of locally and domestically available materials.
2) Laboratory test results exploring the flow, compression and tensile strength, bond strength, and shrinkage of the newly developed UHPC.
3) Guidelines for field mixing and implementation of the developed non-proprietary UHPC.
4) A comprehensive final report.

How will the research results be implemented?

It is recommended to include the UHPC mix design along with its implementation guidelines into relevant ITD documentation.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

UHPC commonly provides enhanced durability, increased strength, and resistance to diverse environmental factors compared to traditional concrete. Although UHPC is generally considered cost-prohibitive, it contributes to prolonged lifespans for various bridge components derived from these advancements. This research seeks to maintain these characteristics while achieving cost reductions by developing a non-proprietary UHPC mix that incorporates locally sourced constituents.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

1) Safety:
    - Construction Workers and Traveling Public: The main benefit of UHPC is its use in Accelerated Bridge Construction (ABC) applications. ABC increases traveling public and worker's safety by lowering exposure to construction activities and increasing mobility and economic opportunities by reducing traffic interruptions and delays.
    - Enhanced Material Durability: UHPC's exceptional durability and resistance to environmental factors can lead to longer-lasting structures, reducing the need for frequent maintenance.
    - Improved Material Performance: UHPC's high strength, bond strength, and toughness contribute to the structural integrity of bridges, enhancing reliability.
2) Economy:
    - Material and Labor Costs: Non-proprietary UHPC will result in lower costs. With the guidelines developed for field application, the labor cost will be reduced. In addition, with the use of the non-preoperatory UHPC, the added cost of an on-site engineer typically required by the propriety UHPC supplier can be eliminated. With proper guidance, this responsibility can be given to the department of transportation bridge project manager and the on-site inspector.
    - Reduced Maintenance Costs: The long lifespan and low maintenance requirements of UHPC can result in cost savings over the life cycle of a structure, making it economically advantageous.

- Extended Service Life: UHPC's ability to resist deterioration can extend the service life of bridges and other constructions, reducing the frequency of replacements and associated costs.

3) Innovation:
    - Customization: UHPC allows for the development of customized mixes to meet specific project requirements, fostering innovation in design and construction.
    - Advanced Applications: The unique properties of UHPC enable the exploration of new construction techniques, such as slender and aesthetically pleasing components, promoting innovative approaches to infrastructure projects.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

The proposed work is expected to yield several practical benefits, including:

1) Safety:
    - Construction Workers and Traveling Public: See above.
    - Incident Records: Track incidents and failures over time, comparing the performance of structures utilizing UHPC with traditional structures to assess safety improvements.
    - Field Inspections: Regularly inspect structures utilizing UHPC in the field to assess their condition, looking for signs of deterioration or issues that may impact safety and performance.
2) Economy:
    - Material and Labor Costs: See above.
    - Life Cycle Cost Analysis: Conduct life cycle cost analyses to compare the total costs of structures utilizing UHPC (including construction, maintenance, and potential replacements) with traditional structures over an extended period.
    - Maintenance Records: Maintain detailed records of maintenance activities and costs for UHPC and traditional structures, comparing the frequency and expenses associated with each.
3) Innovation:
    - Adoption of New Techniques: Monitor the adoption of innovative construction techniques facilitated by UHPC, such as the use of advanced connections and assess their impact on project timelines and costs.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of

research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid.

Is there a well-supported reason the project can/should not be competitively bid?

______ *Yes*
__***X***__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: ____24________ **months**
Estimated Cost for the Project: **$____200,000____**

Project E – The Impacts of Type IL Cement on Bridge Structures

TITLE:

The Impacts of Type IL Cement on Bridge Structures

SUBJECT AREA:

(e.g., Pavements, Bridges, Environment, Maintenance, Safety, Planning, Management, etc.)

Bridges

PROBLEM STATEMENT:

What problem would be addressed by this project?

Portland Limestone Cement (PLC), sometimes referred to as Type IL cement, is a cutting – edge product that is changing the way people in the construction sector utilize concrete. This kind of blended hydraulic cement can have five to fifteen percent limestone content; however, the Idaho Transportation Department (ITD) specifications currently limit this to 12.5% maximum. Although the product has many advantages, it functions in the same way as ordinary Portland cement (OPC) with great benefits. Its 10% lower carbon footprint due to the limestone component is what makes it so well-liked. One of the reasons for its rising popularity in the US is the heightened emphasis on sustainability. Since 2012, it has been available for purchase in the US under the Standard Specification for Blended Hydraulic Cements (ASTM C5952/AASHTO M2403) as a Type IL cement with 5% to 15% inter-ground limestone fines for use in transportation infrastructure. Many states have allowed PLC use as an environmentally acceptable substitute for conventional cement, and more are anticipated to follow soon, according to various Department of Transportations (DOTs). As of 2023, many suppliers in Idaho can only provide Type IL cement and have phased out the production of Type I/II ordinary Portland cements (OPC). This change has put ITD in a position of having to allow the use Type IL cements in proposed mix designs without a clear understanding of the potential consequences or benefits to ITD's infrastructure. While we know that other DOTs have been using the IL cements successfully with comparable results to the OPC, specific questions with regard to the effects on our structures and calculations related to structures have not been researched. There is limited information in the literature about the specifics of implementing IL; especially, as it relates to concrete bridges. IL For example, what will be the effect of using this new type of cement on the shrinkage, creep, camber, and prestressing losses calculations especially for ITD bridges. Various questions still need answers about the long-term performance of Type IL cement in ITD bridge inventory.

How is ITD impacted by the problem?

The aging infrastructure of bridges has driven ITD to allocate significant resources to the rehabilitation and reconstruction of these structures. The national interest to lower carbon footprint is moving on track and many stakeholders are currently replacing ordinary Portland cement with Type IL cement. ITD will be one of the leading state transportation agencies that invest in this critical research area, which touches the sustainability and performance of Idaho bridges over the coming years.

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.

A preliminary literature review was conducted on the current state of practice for the impacts of Type IL cement on bridge structures.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

The objective is to study the effect using Type IL cement on the design of bridge elements considering various aspects such as shrinkage, creep, reinforcement development length, camber calculations, prestressing strand bond length, prestress transfer length, and the prestressing losses. This approach ensures an increase in infrastructure resiliency and lower costs while maintaining the target performance.

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

The project Tasks:

1) Review approved Type IL concrete mixtures and compare the performance with ITD concrete mixtures using OPC. Summarize the test results.

2) Perform a comparison between the Type I/II cement with Type IL cement in terms of mechanical properties, and durability (shrinkage, and creep, permeability and superior meter, calorimetry), in addition, include the effect of SCMs in the mix design for comparison.

3) Test scaled prestressed concrete beams to compare the performance of Type I/II and Type IL cements in prestressed concrete girder applications. The tests should be designed to measure prestress losses, strand transfer length, strand development length, and beam flexural strength.

4) Investigate the effect of the results of Tasks 2 and 3 on the design equations for bridge elements.

What deliverables/outputs will be produced?

1) A thorough overview of the current state of practice in Type IL cement concrete.
2) Laboratory test results exploring the properties of fresh and cured mix designs along with the mechanical and durability performance of the newly developed concrete.
3) Report the impact of the new Type IL cement on the design of Idaho bridges.
4) A comprehensive final report.

How will the research results be implemented?

It is recommended to include the Type IL cement concrete mix designs along with their implementation into relevant ITD documentation.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

The results of this project will put ITD on track for using Type IL cement in bridges and concrete pavements. The implementation of this type of cement will make huge impact on the environment in Idaho by significantly decrease the carbon emission generated from Type I/II cement. The implementation of PLC will also increase the durability and service life of Idaho bridges.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

Compared to ordinary Portland cement (OPC), which satisfies the Standard Specification for Portland Cement (ASTM C150), PLC has a smaller environmental footprint. Up to 10% less carbon dioxide (CO_2) might be released during the manufacturing process of Type IL cements due to the lack of requirement for heating or chemical alteration of limestone particles. Six regions in the U.S. have already set pricing or limitations on greenhouse gas emissions from cement factories due to government legislation. Many American plants have already switched to 100% PLC production, or they soon will. OPC might not be accessible in various locations in the foreseeable future, in which case PLC would be the only choice. ITD is already experiencing this change. In addition, type IL cement has shown excellent durability based on a few studies, which could have significant impact in reducing maintenance costs.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

This study's ultimate goal is a comprehensive document that can be used to help ITD personnel to design bridges using Type IL cement and what will be the long-term performance of Idaho bridges incorporating this new cement type. This research will affect Idaho bridge designers, construction workers, and end users of Idaho infrastructure.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid.

Is there a well-supported reason the project can/should not be competitively bid?

______ *Yes*

__X__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: ___36______ **months**
Estimated Cost for the Project: $___350,000___

Project F – Bridge Deterioration Modeling

TITLE:

Development of Idaho Bridge Deterioration Model

SUBJECT AREA:

(e.g., Pavements, Bridges, Environment, Maintenance, Safety, Planning, Management, etc.)

Bridges, Maintenance, Repair, Rehabilitation, Planning, Safety, Bridge Management

PROBLEM STATEMENT:

What problem would be addressed by this project?

This project aims to address challenges associated with maintenance planning, cost reduction, service life extension, performance monitoring, and asset management. Specifically, the development of an accurate deterioration model aims to (1) enable better predictions of the timing and nature of required bridge maintenance, (2) prevent unnecessary and premature maintenance interventions, (3) help identify potential safety issues in advance, (4) aid in the development of service life extension strategies, and (5) evaluate the severity and extent in which variables influence bridge deterioration rates.

How is ITD impacted by the problem?

ITD can be significantly impacted by the problems associated with inaccurate or non-existent bridge deterioration models. Some key implications are:

1) Budget Allocation Challenges:

    - Inaccurate predictions may lead to misallocation of budgetary resources, as ITD may allocate funds for maintenance based on flawed projections. This can result in overspending on unnecessary repairs or, conversely, insufficient funding for critical maintenance needs.

2) Increased Operational Costs:

    - Unforeseen and premature maintenance interventions can increase operational costs. Unexpected repairs may require urgent out-of-season responses, leading to higher labor and material expenses.

3) Infrastructure Longevity and Resilience:

    - Without accurate deterioration models, ITD may struggle to implement effective strategies for extending the service life of bridges.

4) Public Perception and Trust:

- Unplanned maintenance activities can disrupt the normal operation of bridges, causing traffic delays, closures, and inconvenience to the public. This can result in public dissatisfaction and can wane public trust in ITD's ability to manage and maintain critical infrastructure.

5) Resource Inefficiency:

- ITD may face resource inefficiency by investing in maintenance activities that do not align with actual deterioration patterns. This can lead to wasted resources and an inefficient use of taxpayer money.

LITERATURE SEARCH SUMMARY:

Describe how your proposed research differs from, or will build upon, the existing body of research found in a review of relevant literature (do not include the literature search results). If no search is performed, explain why it was not needed. Literature searches can be conducted on TRID (http://trid.trb.org), which includes the Research in Progress database (http://rip.trb.org/). An excellent resource on conducting literature searches is Transportation Research Circular "E-C194: Literature Searches and Literature Reviews for Transportation Research Projects" (specifically Part I, pages 1-18) available at https://onlinepubs.trb.org/onlinepubs/circulars/ec194.pdf.

A preliminary literature review was conducted on the current state of practice on the development of bridge deterioration models. In particular, the research documents that have been published in the last 10 years are considered.

Many states, including California, Delaware, D.C., Indiana, Kentucky, Michigan, Minnesota, Missouri (Missouri DOT 2022), Montana (Montana DOT 2022)*, Nebraska, Ohio, Wisconsin, and Wyoming have already begun or finished creating bridge deterioration models for their regions (Illinois DOT 2021)*. This proposed research aims to develop a bridge deterioration model specifically tailored to Idaho, considering factors like climate, deicing chemical usage, construction practices, environments, and truck traffic rates.

RESEARCH PROPOSED:

What are the objectives of the proposed project?

This project seeks to develop a probabilistic deterioration model guided by an extensive literature review, and validated by historical bridge data. In addition, this process will identify region-specific factors impacting bridge deterioration rates and assess bridge material performance.

Is the proposed work an extension of past research efforts?

No

What tasks do you envision?

1) Conduct an extensive literature review, exploring specific high-impact variables, model types, and bridge groupings for analysis.

2) Compile a comprehensive database of historical bridge data in Idaho, incorporating information on construction details, maintenance records, and environmental conditions.

3) Analyze factors unique to Idaho that influence bridge deterioration rates, including climate variations, deicing chemical usages and types, construction practices, traffic flow and type, and environment.

4) Develop a probabilistic deterioration model incorporating identified region-specific factors.

5) Validate the newly developed deterioration model using historical bridge data.

6) In collaboration with ITD TAC members, create guidelines for the practical implementation of the deterioration model within ITD's Bridge Management System (BMS).

7) Create a final report summarizing the deterioration model, its validation results, region-specific findings, and guidelines for implementation.

What deliverables/outputs will be produced?

1) A report summarizing the insights gained from the literature review, highlighting relevant studies, methodologies, and best practices.

2) The developed probabilistic deterioration model, including the mathematical framework, algorithms, and parameters used.

3) A report documenting the validation process of the deterioration model, outlining the accuracy, reliability, and limitations of the model.

4) A set of practical guidelines for the implementation of the deterioration model within ITD's BMS.

5) A comprehensive final report summarizing all aspects of the research.

How will the research results be implemented?

It is recommended that this newly developed deterioration model be implemented into ITD's current BMS.

ANTICIPATED BENEFITS/OUTCOMES:

How will the information and deliverables generated from the project be used to solve the problem?

Through integration with ITD's BMS, the newly developed bridge deterioration model would provide insight into when and how a bridge will need to be maintained, including the confidence of each prediction. These predictions can be used to assess the timing and type of bridge maintenance needed, help identify safety issues in advance, guide service life extension strategies, and gauge the impact of various bridge properties on bridge deterioration rates.

How will the proposed research further the accomplishment of ITD's long-range goals and/or key focus areas?

1) Safety:
   - Accurate bridge deterioration predictions reduce the risk of unexpected failures and facilitate proactive maintenance.
2) Economic Mobility:
   - The ability to predict bridge deterioration rates would promote efficient resource allocation, ensuring that limited resources are directed toward critical infrastructure needs.
3) Innovation:
   - Considering region-specific factors in an accurate deterioration model would go beyond generic approaches. This showcase of innovation would present customized solutions for each region, allowing for an in-depth analysis of the impacts of various bridge properties on bridge deterioration rates.

What practical benefits will result from the work proposed, and how can they be measured? (cost savings, process efficiencies, accidents reduced, lives saved, etc. – please be specific)

The following benefits can be measured by comparing maintenance schedule, infrastructure service life, number of unexpected failures, and costs before and after the implementation of a new bridge deterioration model into ITD's BMS:

1) Optimized Maintenance Planning.
2) Cost Reduction.
3) Extended Infrastructure Service Life.
4) Enhanced Safety Measures.

RESEARCHER/CONSULTANT SELECTION:

Note - Research may be conducted by universities or private research firms. New legislation (section 67-2332A, Chapter 23, Title 67 of Idaho Statute) requires that contracts with Idaho universities be competitively solicited. Due to this requirement, the ITD Research Program competitively bids contracts of

research projects. Problem statements need to be developed in-house by department staff to help ensure a level playing field when projects are put out to bid.

Is there a well-supported reason the project can/should not be competitively bid?

______ *Yes*

__X__ *No*

If you selected yes, please explain the unique qualifications of the researcher or circumstances that would support a sole source selection or exemption from competitive bidding requirements.

ESTIMATE RESEARCH PERIOD AND FUNDING NEEDED:

Estimated Length of Project: ___24______ **months**
Estimated Cost for the Project: **$___150,000___**

4. Summary and Conclusions

To select six projects for ITD's RAC review that support their research needs and priorities, seven tasks were established:

1. Host a kick-off meeting.
2. Develop an understanding of ITD's bridge program.
3. Determine DOT bridge program best practices and literature review.
4. Identify critical knowledge gaps.
5. Determine and prioritize ITD bridge section research needs.
6. Prepare draft research requests for selected research topics using ITD's research PRFs.
7. Prepare and present a final report.

The conclusions and observations of two tasks were used to direct research suggestions to ensure ITD priorities and research needs are met. These tasks include (1) determine DOT bridge program best practices and literature review and (2) Identify critical knowledge gaps.

To determine DOT bridge program best practices, a list of current research efforts in out-of-state DOTs was compiled. This included 857 recently concluded and ongoing projects that focus on bridges and transportation structures from the Transportation Research Board (TRB). To ensure a current and relevant project list, the projects selected from the TRB were limited to projects completed within the past five years. Subsequently, these projects underwent three distinct filtering and ranking processes:

1. Filtering from 857 to 208
    - The initial list of 857 projects underwent ranking from the project research team. Each project was ranked for relevancy from zero to five with five being the most relevant. Once done, projects ranked below three were removed, leaving 208 projects.
2. Filtering from 208 to 79
    - To further refine the project list, two meetings were held with ITD's TAC members and the principal investigator to discuss the relevancy of each project. Projects were then selected to be kept on a yes/no basis, leading to 79 projects left.
3. Filtering from 79 to 25
    - The third filtering effort was done by ITD's TAC members and one member of the research team. The remaining 79 projects were rating once more from zero to five to apply relevancy to the following two questions: (A) "Is the project applicable to ITD's inventory and will the results of the project be likely to benefit ITD?" and (B) "Is there a need for ITD

to perform a similar project, given that the research is completed or in progress elsewhere?”. The projects were then organized by the ranks for question B and the top twenty-five underwent a moderate literature review.

The following is the list of top 25 ranked projects: (1) Reduce Concrete Cracking Through Mix Design, (2) Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements, (3) Evaluate Bridge Deck Condition and Replacement Methods, (4) Mitigation Strategies for Cracking in Concrete Bridge Decks, (5) Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials, (6) Implementation of Bridge Preservation Actions, (7) Computer Vision Tools for Bridge Inspections and Reporting, (8) Precast Pier System for Accelerated Bridge Construction in Idaho, (9) Durability and Volumetric Stability of Non-Proprietary Ultra High-Performance Concrete Mixes Batched with Locally Sourced Materials, (10) Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies, (11) Evaluation of Bridge Rail Systems to Confirm AASHTO MASH Compliance, (12) Testing and evaluation of energy absorbing panels for over-height collision impact protection, (13) Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology, (14) Significant Factors of Bridge Deterioration, (15) Development of Deterioration Curves for Bridge Elements in Montana, (16) Feasibility of 3D Scanning Technology for Bridge Inspection and Management, (17) Vision-Based Detection of Bridge Damage Captured by Unmanned Aerial Vehicles, (18) Aerial Infrared Scanning of Bridge Decks for Detecting and Mapping Delamination, (19) Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands, (20) Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking, (21) Data-Driven Decision-Making Framework for Inspection of Bridge Decks, (22) Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails, (23) Accelerated Sulfate Attack Testing for Concrete, (24) Repair and Strengthening of Bridge Girders using Ultra-High-Performance Concrete (UHPC), (25) Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete. A moderate literature review for each of the twenty-five projects was conducted to ensure relevancy. After a review of the projects and their respective ranks, it was suggested that TAC members valued projects focusing on bridge decks and construction materials. In addition, organizing the projects by categories suggested that bridge decks were the highest priority.

Identifying critical knowledge gaps involved surveying out-of-state DOTs and evaluating the element of deficiently rated bridges in Idaho. The DOT survey focused on bridge funding, research priorities, and impacts, revealing a diverse range of research focus areas among DOTs. Notably, bridge deck and superstructure funding emerged as the highest priorities, along with an average allocation of sixteen percent in various pooled funded projects. The report on deficiently rated bridge elements detailed the current condition state of elements in deficiently rated bridges, highlighting substructure elements such as reinforced concrete abutments, pier walls, and pile caps as the most severely conditioned. It speculates that frequent repairs and/or replacements of bridge decks, bearings, and rails might prevent the progression of these elements to more severe condition states.

In order to develop research suggestions that emphasize ITD priorities, twenty-three project topics were solicited from the research team and TAC members using the conclusions and observations from the previous two tasks as guides. These suggestions were then discussed and ranked with the top six being selected for review and submission to ITD's RAC. The top ranked six projects were: (1) Evaluate ITD's Bridge Deck Preservation Strategies, (2) Implementation of Internal Concrete Curing (ICC) to Enhance Concrete Performance, (3) Development of More Reliable Camber Prediction for Prestressed Deck Bulb-T girders, (4) Use of Non-Proprietary Ultra-High Performance Concrete in Idaho Bridges, (5) The Impacts of Type IL Cement on Bridge Structures, and (6) Bridge Deterioration Modeling. Each of these projects were given a moderate literature review followed by the completion of a PRF draft. In March 2024, PRFs for the first two projects were submitted to ITD's Research Advisory Committee (RAC) for possible approval for the following year.

5. Cited Works

Aitcin, P.C., 2003. “The durability characteristics of high-performance concrete: a review.” *Cement and Concrete Composites*, 25(4), May-July 2003, pp. 409-420. Accessed December 27, 2023. https://doi.org/10.1016/S0958-9465(02)00081-1.

Alaska Department of Transportation. 2023. *Aerial Infrared Scanning of Bridge Decks on Parks Highway to Map Delaminations.* Carmichael, Adam, and Spencer Bates. FHWA-AK-RD-000S. Accessed March 3, 2024. https://dot.alaska.gov/stwddes/research/assets/pdf/000S_960.pdf.

Arkansas Department of Transportation. 2019. *Estimating Camber, Deflections, and Prestress Losses in Precast Prestressed Bridge Girders*. Mohammedi, Ahmed, and Micah W. Hale. TRC1606. Accessed December 4, 2023. https://rosap.ntl.bts.gov/view/dot/59113.

ASTM C78/C78M-22. 2022. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). ASTM International.

BASF. 2023. 4×4 Concrete for Strength-on-Demand. BASF Corporation. Accessed November 13, 2023. https://www.master-builders-solutions.com/en-us/functions-and-applications/producing-concrete/4x4-concrete-for-strength-on-demand.

Bentz, D.P., 2007. “Internal curing of high-performance blended cement mortars.” *ACI Materials Journal*, 104(4), p. 408. Accessed December 28, 2023. https://www.researchgate.net/profile/D-Bentz/publication/234834802_Internal_Curing_of_High-Performance_Blended_Cement_Mortars/links/0fcfd510150ad99f2a000000/Internal-Curing-of-High-Performance-Blended-Cement-Mortars.pdf?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19.

Bentz, D.P. and Weiss, W.J., 2011. Internal curing: a 2010 state-of-the-art review. US Department of Commerce, National Institute of Standards and Technology. Accessed December 29, 2023. https://nvlpubs.nist.gov/nistpubs/Legacy/IR/nistir7765.pdf.

California Department of Transportation. 2019. *Investigation of Polyester Concrete Overlay Rehabilitation Strategy to Extend the Service Life of Concrete Bridge Decks.* Cuelho, Eli, and Jerry Stephens. Caltrans Project 65A0490. Accessed November 14, 2023. https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/final-reports/ca19-2543-finalreport-a11y.pdf.

Chiarito, Vincent. “Develop Countermeasure Strategies for Protecting Bridge Girders Against Overheight Vehicles Impact.” Transportation Pooled Fund. Accessed March 3, 2024. https://www.pooledfund.org/Details/Study/712.

Choudhary, A., Ghantous, R., Opdahl, H., Burkan Isgor, O., Weiss, j. 2022.Heat of Hydration, Shrinkage, and Flexural Strength of Portland Limestone Cement Mortar. Adv. Civ. Eng. Matls. Apr 2022, 11(1): 501-519 (19 pages).

Cost, Tim, Gary Knight, Wayne Wilson, Jay Shannon, and Isaac Howard. 2013. “Performance of Typical Concrete Mixtures for Transportation Structures as Influenced by Portland-Limestone Cement from Five Sources.” Presented at the Internation Concrete Sustainability Conference, San Fransisco, California, 2013. Accessed February 23, 2024. https://cdn-wordpress.webspec.cloud/intrans.iastate.edu/uploads/2018/08/Tues06b-Cost-et-al-paper-submission.pdf.

Federal Highway Administration. 2013. *Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector*. Wille, Key and Christopher Boisvert-Cotulio. FHWA-HRT-13-100. Accessed December 26, 2023. https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB2013110587.xhtml#.

Federal Highway Administration. 2016. *Current Information on the Use of Overlays and Sealers.* Lane, Susan. FHWA-HRT-16-079. Accessed November 12, 2023. https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/16079/16079.pdf.

Federal Highway Administration. 2018. *Properties and Behavior of UHPC-Class Materials*. Haber, Zachary, Igor De la Varga, Benjamin A. Graybeal, Brian Nakashoji, and Rafic El-Helou. FHWA-HRT-18-036. Accessed December 26,2023. https://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/18036/18036.pdf.

Federal Highway Administration. 2023. *Bridge Inspector’s Reference Manual.* Ryan, Thomas W., Cassandra E. Lloyd, Michael S. Pichura, Darrin M. Tarasovich, and Sandy Fitzgerald. FHWA-NHI-23-024. Accessed October 3, 2023. https://www.fhwa.dot.gov/bridge/nbis/pubs/nhi23024.pdf.

Federal Highway Administration. 2023. *Portland Limestone Cement.* Cooper, Michelle, and Robert Spragg. FHWA-HRT-23-104. Accessed April 1, 2024. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-104.pdf.

Garcia, Jose E., Nicolas B. Tiburzi, Kevin J. Folliard, and Thanos Drimalas. 2022. “Mechanical Properties and electrical resistivity of Portland limestone cement concrete systems containing greater than 15% limestone and supplementary cementitious materials.” *Journal of cement 8,* (2002) issue 100026. Accessed March 22, 2024. https://www.sciencedirect.com/science/article/pii/S2666549222000068.

Georgia Department of Transportation. 2016. *Assessment of High Early Strength Limestone Blended Cement for Next Generation Transportation Structures.* Shalan, Ahmad, Lawrence F. Kahn, Kimberly Kurtis, and Elizabeth Nadelman. FHWA-GA-17-1433. Accessed February 24, 2024. https://rosap.ntl.bts.gov/view/dot/31925.

HiPer Fiber. 2023. *UHPC Recipe & Resources.* Accessed December 28, 2023. https://hiperfibersolutions.com/uhpc/.

Idaho Transportation Department. 1988. *Camber Growth Prediction in Precast Prestressed Concrete Bridge Girders.* Brown, Krista M. UMI Number 9914955. Accessed December 4, 2023. https://apps.itd.idaho.gov/apps/research/Completed/RP128.pdf.

Idaho Transportation Department. 2021. *A Precast Pier System for Accelerated Bridge Construction (ABC) in Idaho*. Mashal, Mustafa, Arya Ebrahimpour, Mahesh Acharya, Jared Cantrell, Corey Marshall, Ali Shokrgozar. FHWA-ID-21-281. Accessed March 3, 2024. https://rosap.ntl.bts.gov/view/dot/63530/dot_63530_DS1.pdf.

Idaho Transportation Department. 2023. *Standard Specifications for Highway Construction*. Accessed November 12, 2023. https://apps.itd.idaho.gov/Apps/manuals/SpecBook/SpecBook23.pdf.

Illinois Center for Transportation. 2016. *Bridge Decks: Mitigation of Cracking and Increased Durability*. Ardeshirilajimi, Ardavan, Di Wu, Piyush Chaunsali, Paramita Mondal, Ying T. Chen, Mohammad M. Rahman, Ahmed Ibrahim, Will Lindquist, and Riyadh Hindi. FHWA-ICT-16-016. Accessed January 24,2024. https://apps.ict.illinois.edu/projects/getfile.asp?id=4980.

Illinois Department of Transportation. 2021. *Evaluation of Illinois Bridge Deterioration Models.* Fu, Gongkang. FHWA-ICT-21-024. Accessed January 12, 2024. https://apps.ict.illinois.edu/projects/getfile.asp?id=9841.

Indiana Department of Transportation. 2013. *Documentation of the INDOT Experience and Construction of the Bridge Decks Containing Internal Curing in 2013*. Barrett, Timothy J., Albert E. Miller, and Jason W. Weiss. FHWA/IN/JTRP-2015/10. Accessed December 28, 2023. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3088&context=jtrp.

Indiana Department of Transportation. 2016. *Bridge Deterioration Models to Support Indiana's Bridge Management System*. Moomen, Milhan, Yu Qiao, Bismark R. Agbelie, Samuel Labi, and Kumares C. Sinha. FHWA/IN/JTRP-2016/03. Accessed March 4, 2024. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3113&context=jtrp.

Indiana Department of Transportation. 2023. *Implementing epoxy injection in concrete overlaid bridge decks.* Baah, Prince. FHWA/IN/JTRP-2023/03. Accessed January 24, 2024. https://doi.org/10.5703/1288284317588.

Iowa Department of Transportation. 2015. *Improving the Accuracy of Camber Predictions for Precast Pretensioned Concrete Beams.* Honarvar, Ebadollah, James Nervig, Wenjun He, Sri Sritharan, and Jon Matt Rouse. IHRB Project TR-625. Accessed December 4, 2023. https://rosap.ntl.bts.gov/view/dot/29403.

Iowa Department of Transportation. 2016. *Investigation of Techniques for Accelerating the Construction of Bridge Deck Overlays*. Phares, Brent, Travis Hosteng, Lowell Greimann, and Anmol Pakhale.

InTrans Project 14-500. Accessed November 13, 2023. https://cdn-wordpress.webspec.cloud/intrans.iastate.edu/uploads/2018/03/accelerating_bridge_deck_overlay_construction_w_cvr.pdf.

Iowa Department of Transportation. 2019. *Investigation and Evaluation of Iowa Department of Transportation Bridge Deck Epoxy Injection Process*. Wipf, Terry J., Brent Phares, Justin M. Dahlberg, and Ping Lu. InTrans Project 10-381. Accessed November 14, 2023. https://intrans.iastate.edu/app/uploads/2019/02/bridge_deck_epoxy_injection_process_w_cvr.pdf.

Jayaseela, H., and Bruce, W. R. 2007. Prestress losses and the estimation of long-term deflections and camber for prestressed concrete bridges final report. Design, Oklahoma State.

Kansas Department of Transportation. 2020. *Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology*. Lafikes, James, David Darwin, Matthew O'Reilly, Muzai Feng, Alireza Bahadori, and Rouzbeh Khajehdehi. FHWA-KS-20-04. Accessed March 3, 2024. https://www.ksdot.gov/Assets/wwwksdotorg/bureaus/KdotLib/2023/FHWA-KS-23-02_SummaryReport.pdf.

Lim, Sung Yeob. 2021. "Ultra-high Performance Concrete (UHPC) for Closure Pours between Precast." M.S. thesis, Dept. of Civil and Environmental Engineering, Georgia Institute of Technology. Accessed December 28, 2023. https://repository.gatech.edu/bitstreams/c281f737-567f-4a1c-a32b-f785209c74d8/download.

Louisiana Department of Transportation. 2016. *Evaluation of Portland Cement Concrete with Internal Curing Capabilities*. Rupnow, Tyson, Zachary Collier, Amar Raghavendra, and Patrick Icenogle. FHWA/LA.16/569. Accessed January 24, 2024. https://www.ltrc.lsu.edu/pdf/2016/FR_569.pdf.

Martin, L. D. 1977. A Rational Method for Estimating Camber and Deflection for Precast Prestressed Members. PCI Journal, 22(1), 00-108.

Michigan Department of Transportation. 2016. *A process for Systematic Review of Bridge Deterioration Rates*. Kelley, Robert. Accessed March 3, 2024. https://www.michigan.gov/mdot/-/media/Project/Websites/MDOT/Programs/Bridges-and-Structures/Mgmt-and-Scoping/Process-Systematic-Review-Bridge-Deterioration-Rates.pdf?rev=21edea9f3e154859999a88fc74a6f613&hash=0CC04A86FB52FD6F3D45E2B04A9B165B.

Michigan Department of Transportation. 2018. *Commercial Production of Non-Proprietary Ultra High Performance Concrete*. El-Tawil, Sherif, Yuh-Shiou Tai, Bo Meng, Will Hansen and Zhichao Liu. RC-1670. Accessed December 27, 2023. https://rosap.ntl.bts.gov/view/dot/42751/dot_42751_DS1.pdf.

Mississippi Department of Transportation. 2019. *Best Practices for Estimating Camber of Bulb T and Florida Girders*. Tomley, David A. State Study No. 288. Accessed December 4, 2023. https://mdot.ms.gov/documents/Research/Reports/Interim%20&%20Final/State%20Study%20288%20-%20Best%20Practices%20for%20Estimating%20Camber%20of%20Bulb%20T%20and%20Florida%20Girders.pdf.

Missouri Department of Transportation. 2018. *Design and Performance of Cost Effective Ultra High Performance Concrete for Bridge Deck Overlays.* Khayat, Kamal H. and Mahdi Valipour. Project TR201704. Accessed November 13, 2023. https://rosap.ntl.bts.gov/view/dot/36265/dot_36265_DS1.pdf.

Missouri Department of Transportation. 2021. *Enhanced Camber Calculations for Prestressed Concrete Bridge Girders.* Orton, Sarah, Vellore Gopalaratnam, Ali Elawadi, John Holt, Maria Lopez, Thomas Murphy. CMR 21-011. Accessed December 4, 2023. https://spexternal.modot.mo.gov/sites/cm/CORDT/cmr21-011.pdf.

Missouri Department of Transportation. 2022. *Evaluation of Missouri's NBI Data to Predict the Deterioration of Bridges.* Washer, Glenn, John Meyers, Mohammad Hammed, and Henry Brown. TR202012. Accessed January 18, 2024. https://rosap.ntl.bts.gov/view/dot/63366/dot_63366_DS1.pdf.

Missouri Department of Transportation. 2023. *Performance of Cost-Effective Non-Proprietary UHPC in Thin-Bonded Bridge Overlays.* Khayat, Kamal H., Le Teng, and Alfred Addai-Nimoh. Project TR202121. Accessed November 16, 2023. https://spexternal.modot.mo.gov/sites/cm/CORDT/cmr23-011.pdf.

Montana Department of Transportation. 2017. *Development for Non-Proprietary Ultra-High Performance Concrete.* Berry, Michael, Richard Snidarich, and Camylle Wood. FHWA-MT-17-010. Accessed December 26, 2023. https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/BRIDGE_UHPC/FINAL_REPORT.PDF.

Montana Department of Transportation. 2021. *Feasibility of Non-Propriety Ultra-High Performance Concrete (UHPC) for use in Highway Bridges in Montana: Phase II Field Application.* Berry, Michael, Riley Scherr, and Kirsten Matteson. FHWA-MT-21-002. Accessed January 04, 2024. https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/BRIDGE_UHPC_2/Final-Report.PDF.

Montana Department of Transportation. 2022. *Development of Deterioration Curves for Bridge Elements in Montana.* Fick, Damon, and Matthew Bell. FHWA-MT-22-003. Accessed March 3, 2024. https://www.mdt.mt.gov/other/webdata/external/research/DOCS/RESEARCH_PROJ/BRIDGE_UHPC_2/Final-Report.PDF.

Montana Department of Transportation. 2023. *Feasibility of Non-Propriety Ultra-High Performance Concrete (UHPC) for use in Highway Bridges in Montana: Implementation.* Berry, Michael, Elias Hendricks, and Kirsten Matteson. FHWA-MT-23-002. Accessed January 04, 2024. https://mdt.mt.gov/other/webdata/external/research/docs/research_proj/DETERIORATION-CURVES/Final-Report.pdf.

Naaman, Antoine E. Prestress Concrete Analysis and Design: Fundamentals. Second Edition. Techno Press 3000, Ann Arbor MI, 2004.

National institute of Standards and Technology. 2002. *Influence of curing conditions on water loss and hydration in cement pastes with and without fly ash substitution*. Bentz P., Dale. NISTIR 6886. Accessed December 28, 2023. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860431.

Nebraska Department of Transportation. 2020. *Feasibility Study of Development of Ultra-High Performance Concrete (UHPC) for Highway Bridge Applications in Nebraska*. Morcous, George, Jiong Hu, Mostafa A. El-Khier, and Flavia Mendonca. SPR-P1(18) M072. Accessed January 04, 2024. https://dot.nebraska.gov/media/3ohmo534/m072-uhpc-project-final-report.pdf.

Nebraska Department of Transportation Research Reports. 2020. *Application of Internal Curing to Improve Concrete Bridge Deck Performance*. Abdigaliyev, Arman, Yong-Rak Kim, and Jiong Hu. SPR-P1(19) M083. Accessed December 23, 2023. https://digitalcommons.unl.edu/ndor/253.

Nguyen, H., Stanton, J., Eberhard, M., and Chapman, D. 2015. "The effect of temperature variations on the camber of precast, prestressed concrete girders." PCI Journal, 60(5), 48–64.

North Carolina Department of Transportation. 2011. *Predicting Camber, Deflection, and Prestress Losses in Prestressed Concrete Members*. Rizkalla, Sami, Paul Zia, and Tyler Storm. Research Project# 2010-05. Accessed December 4, 2023. https://connect.ncdot.gov/resources/Structures/Structures%20Documents/NCSU%20Final%20Report%20-%20Predicting%20Camber.pdf.

North Carolina of Transportation. 2015. *Determination of Bridge Deterioration Models and Bridge User Costs for the NCDOT Bridge Management System.* Cavalline, L. Tara, Matthew J. Whelan, Brett Q. Tempest, Raka Goyal, and Joshua D. Ramsey. FHWA-NC-2014-07. Accessed January 18, 2024. https://connect.ncdot.gov/projects/research/RNAProjDocs/2014-07FinalReport.pdf.

Oregon Department of Transportation. 2013. *Internal Curing of High-Performance Concrete for Bridge Decks*. Ideker, Jason H., Tyler Deboodt, and Tengfei Fu. FHWA-OR-RD-13-06. Accessed November 13, 2023. https://rosap.ntl.bts.gov/view/dot/25824/dot_25824_DS1.pdf.

Shaker, Fatima, Ahmed Rashad, and Mohamed Allam. 2017. "Properties of concrete incorporating locally produced Portland limestone cement." *Ain Shams Engineering Journal 9,* (2018) page 2301-2309. Accessed March 12, 2024. https://www.sciencedirect.com/science/article/pii/S2090447917300801.

Shokrgozar, A. 2023. "Bond Strength Behavior Between Non-Proprietary UHPC and High Strength Precast Concrete Bridge Components." Ph.D. Dissertation, Dept. of Civil and Environmental Engineering, Idaho State University.

Stallings, J. M., Barnes, R. W., and Eskildsen, S. 2003. "Camber and Prestress Losses in Alabama HPC Bridge Girders." PCI Journal, 48(5), 90–104.

Tadros, M.K. 2015. Camber Variability in Prestressed Concrete Bridge Beams" Concrete Bridge Technology, ASPIRE Spring 2015, pp. 38-42.

Texas Department of Transportation. 2020. *Bridge and Culvert Deterioration Models Using National Bridge Inventory Data.* Weissmann, Jose, Angela J. Weissmann, Arturo H. Montoya. FHWA-TX-20-6979-2. Accessed January 17, 2024. https://library.ctr.utexas.edu/hostedpdfs/texastech/0-6979-1.pdf.

Transportation Research Board. "Research In Progress." National Academies. Accessed March 3, 2024. https://rip.trb.org/.

U.S. Department of Transportation. 2022. *Non-Proprietary Ultra-High Performance Concrete Mix Design for ABC Applications*. Shafei, Behrouz, Karim Rizwan. 69A3551747121. Accessed January 04, 2024. https://abc-utc.fiu.edu/wp-content/uploads/2022/03/non-proprietary_UHPC_mix_design_for_ABC_applications_w_cvr-Revised.pdf.

Virginia Department of Transportation. 2017. *Performance of Bridge Deck Overlays in Virginia: Phase I: State of Overlays.* Balakumaran, Soundar S.G., Richard E. Weyers, and Michael C. Brown. VTRC 17-R17. Accessed November 13, 2023. https://www.virginiadot.org/vtrc/main/online_reports/pdf/17-r17.pdf.

Washington State Bridge Inspection Manual. 2023. M 36-64.14. Accessed March 6, 2024. https://www.wsdot.wa.gov/publications/manuals/fulltext/M36-64/BridgeInspection.pdf.

Washington State Department of Transportation. 2016. *Developing Connections for Longitudinal Joints between Deck Bulb Tees – Development of UHPC Mixes with Local Materials.* Qiao, Pizhong, Zhidong Zhou, and Srinivas Allena. WA-RD 869.1. Accessed January 9, 2024. https://rosap.ntl.bts.gov/view/dot/34546/dot_34546_DS1.pdf.

Washington State Department of Transportation. 2018. *Bridge Element Deterioration of Concrete Substructures*. O'Leary, Micaylla and Jill Walsh. WA-RD 893.1. Accessed March 5, 2024. https://www.wsdot.wa.gov/research/reports/fullreports/893-1.pdf.

Wisconsin Department of Transportation. 2021. *Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking*. Pacheco, Jose, Pavan Vaddey, Kamran Amini, and Jan Vosahlik. WHRP 0092-19-02. Accessed January 24, 2024. https://rosap.ntl.bts.gov/view/dot/62607/dot_62607_DS1.pdf.

Appendix A. DOT Projects Ranked by TAC Members

Round 1 Rankings (857 Projects)

Project Number (from the original list) and Name	Ave Rank
177. PROJECT: Mitigation Strategies for Cracking in Concrete Bridge Decks	5.0
36. PROJECT: Use of Fiber-Reinforced Polymer Composites for Bridge Repairs in Montana	4.8
67. PROJECT: Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology	4.8
44. PROJECT: Evaluate Bridge Deck Condition and Replacement Methods	4.6
221. PROJECT: Ultra-High Performance Concrete Connections Between Precast Bridge Deck Elements	4.6
630. PROJECT: Cost-effective Bridge Decks for Improved Durability and Extended Service Life	4.6
761. PROJECT: Precast Pier System for Accelerated Bridge Construction in Idaho	4.6
32. PROJECT: High Bond Steel Fibers for Ultra High Performance Concrete (UHPC)	4.4
37. PROJECT: Significant Factors of Bridge Deterioration	4.4
46. PROJECT: Reduce Concrete Cracking through Mix Design	4.4
54. PROJECT: Reducing the Cost and Facilitating Broader Adoption of Ultra-High-Performance Concrete (UHPC) in Bridges	4.4
73. PROJECT: Durability and Volumetric Stability of Non-Proprietary Ultra High Performance Concrete Mixes Batched With Locally Sourced Materials	4.4
80. PROJECT: Mitigating Cracks in Concrete Members for Durable Bridge Construction	4.4
144. PROJECT: Stainless Steel Coated Rebar for Chloride Resistant Concrete Highways and Bridges	4.4
147. PROJECT: Designing and Characterizing New Coating Materials to Increase the Corrosion Resistance of Steel Reinforcement Embedded in Concrete	4.4
387. PROJECT: Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts (OHTI)	4.4
559. PROJECT: Long-term Performance of HES Class 50AF Concrete with Polypropylene Fibers as Field-Cast Connection between Deck Bulb-T Girders in SH-36 Bridge over Bear River	4.4
8. PROJECT: Implementation of Bridge Preservation Actions	4.2
25. PROJECT: Computer Vision Tools for Bridge Inspections and Reporting	4.2
47. PROJECT: SPR-4718: Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete	4.2
68. PROJECT: Performance Evaluation of Reinforced Concrete Box Culverts	4.2

Project Number (from the original list) and Name	Ave Rank
114. PROJECT: Repair and Strengthening of Bridge Girders Using Ultra-High-Performance Concrete (UHPC)	4.2
434. PROJECT: Rehabilitation of Deteriorated Bridge Decks with Ultra-High Performance Concrete Overlays	4.2
501. PROJECT: Fatigue Life Analysis of Reinforced Concrete Beams Strengthened with Composites	4.2
532. PROJECT: Performance of ABC Columns and Cost-Effective Retrofit Strategies Subjected to Synergistic Distress Resulting From Corrosion and Seismic Loading	4.2
51. PROJECT: Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands	4.0
86. PROJECT: The Influence of Vehicular Live Loads on Bridge Performance	4.0
101. PROJECT: Legal Truck Load Ratings for Standard Reinforced Concrete Boxes and Rigid Frame Boxes for HL-93 Loading	4.0
143. PROJECT: Experimental Validation of Repair Methods for Earthquake-Damaged Bridges Incorporating ITD’s Precast Pier System	4.0
227. PROJECT: 2292 Innovative Multi-Hazard Resistant Bridge Columns for Accelerated Bridge Construction	4.0
282. PROJECT: Exploration of UHPC Applications for Montana Bridges	4.0
330. PROJECT: Performance of Cost-Effective Non-Proprietary UHPC in Thin Bonded Bridge Overlay	4.0
381. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	4.0
494. PROJECT: Fiber Reinforced Concrete Overlays for Bridge Structures	4.0
506. PROJECT: Alternative High Early Strength Concrete (HESC) Structural Overlays	4.0
535. PROJECT: Guide to Remediate Bridge Deck Cracking	4.0
569. PROJECT: Reliability of ABC Grouted Coupler Connected Bridge Piers Subject to Vehicular Impact	4.0
583. PROJECT: Evaluation of Thin Polymer Overlays for Bridge Decks	4.0
715. PROJECT: UHPC Thin Bonded Overlay on Deteriorated Bridge Decks	4.0
816. PROJECT: Development and Testing of High / Ultra-High Early Strength Concrete for durable Bridge Components and Connections (2.5)	4.0
129. PROJECT: Steel-Free Concrete Bridge Decks (3.18)	3.8
132. PROJECT: Develop Countermeasure Strategies for Protecting Bridge Girders Against Overheight Vehicles Impact	3.8
198. PROJECT: Rapid Post-Earthquake Displacement-Based Assessment Methodology for Bridges Phase I	3.8
241. PROJECT: Identification of Maintenance Practices to Impede Corrosion Impacts on Prestressed Concrete Box Beam Bridges	3.8
297. PROJECT: SPR-4532: Synthesis Study: Repair and Durability of Fire Damaged Prestressed Concrete Bridge Girders	3.8
676. PROJECT: Evaluating Integral Abutment Performance	3.8
726. PROJECT: Performance Evaluation of Polyester Polymer Concrete Overlays Continuation Proposal Phase II TR-772	3.8
784. PROJECT: Performance of Earthquake-Damaged Reinforced Concrete Bridges with Repaired Columns	3.8

Project Number (from the original list) and Name	Ave Rank
788. PROJECT: Fiber-Reinforced Concrete in Bridge Decks TR-767	3.8
9. PROJECT: Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails	3.6
12. PROJECT: Earthquake-Induced Bridge Displacements	3.6
20. PROJECT: Effective Timelines and Contractual Strategies for Accelerated Bridge Construction Projects	3.6
35. PROJECT: SPR-4731: Feasibility of 3D Scanning Technology for Bridge Inspection and Management	3.6
42. PROJECT: Shake Table Tests of Unique High-Strength Reinforced Piers	3.6
66. PROJECT: Laboratory Characterization of Fiber-Reinforced Polymer Reinforcement Material Properties and Surface Treatment Behavior in Concrete	3.6
87. PROJECT: Utilization of 300 ksi Strands for TxDOT Prestressed Girders	3.6
93. PROJECT: Evaluate Performance of Sealers and Coatings Applied to TxDOT Bridge Substructures	3.6
95. PROJECT: Develop/Refine Design Provisions for Headed and Hooked Reinforcement	3.6
97. PROJECT: Vision-Based Detection of Bridge Damage Captured by Unmanned Aerial Vehicles (1.18)	3.6
99. PROJECT: Evaluation of Multi-Layer Polymer Concrete Overlays	3.6
103. PROJECT: Evaluation of Structural Adhesives as "Steel Grouting" in Steel Bridge Repairs	3.6
104. PROJECT: Design of Stud Shear Connectors in Composite Steel Bridges	3.6
135. PROJECT: Development of Improved Inspection Techniques using LiDAR for Deteriorated Steel Beam Ends	3.6
138. PROJECT: Post-Fire Damage Inspection of Concrete Structures - Phase III - In-Situ Experimental Phase	3.6
199. PROJECT: Impact of Response Spectra Definitions and Direct Displacement-Based Design Simplification for Multi-Span Bridges	3.6
200. PROJECT: Bridge Deck Preservation Portal	3.6
219. PROJECT: Field Trials for Cost-Effective Strengthening of SC Load Posted Bridges	3.6
283. PROJECT: Design and Development of High-Performance Composites for Improved Durability of Bridges in Rhode Island (2.17)	3.6
309. PROJECT: Mitigating Cracking in Ultra-High Performance Concrete (UHPC) Bridge Connections	3.6
369. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	3.6
531. PROJECT: Fiber Reinforced Polymer (FRP) Seismic Retrofit of Reinforced Concrete Bridge Columns Vulnerable to Long-duration Subduction Zone Earthquakes	3.6
567. PROJECT: Effectiveness of Concrete Bridge Deck Sealants	3.6
575. PROJECT: Durable Bridges Using Glass Fiber Reinforced Polymer and Hybrid Reinforced Concrete Columns	3.6
585. PROJECT: Durability Assessment of Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Repairs in Bridge	3.6
620. PROJECT: Performance of Earthquake-Damaged Reinforced Concrete Bridges with Repaired Columns – Phase II	3.6

Project Number (from the original list) and Name	Ave Rank
686. PROJECT: Development of Bridge Load Testing Program for Load Rating of Concrete Bridges	3.6
702. PROJECT: Strengthening of Pre-Tensioned Concrete Beams	3.6
716. PROJECT: Utilizing Steel Fibers as Concrete Reinforcement in Bridge Decks	3.6
758. PROJECT: Assessment of Asbestos Containing Materials in Idaho Bridges	3.6
760. PROJECT: Development of General Guidelines on The Effects of Bridge Span Range and Skew Angle Range on Integral Abutment Bridges (IABs) (3.7)	3.6
773. PROJECT: Development of Non-Proprietary UHPC Mix – Evaluation of the Shear Strength of UHPC (University of Washington)	3.6
801. PROJECT: Repair Methods for Corrosion-Damaged Prestressed Concrete Girders	3.6
818. PROJECT: Textured Epoxy Coated and Galvanized Reinforcement to Reduce Cracking in Concrete Bridge Decks and Components	3.6
16. PROJECT: Achieving Resilient Multi-Span Bridges by using Buckling-Restrained Braces	3.4
43. PROJECT: Impact Test of GFRP Reinforced Bridge Barriers	3.4
48. PROJECT: Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies	3.4
55. PROJECT: Design of Continuity Diaphragms Following New AASHTO Provisions	3.4
64. PROJECT: Structural Monitoring of Steel-Member Bridges with Fatigue Life Prognosis due to Dynamic Vehicular Loads	3.4
65. PROJECT: Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements	3.4
78. PROJECT: Capacity Prediction of Repaired and Unrepaired Bridge Beams with Deteriorated Ends	3.4
130. PROJECT: CT Girder Web Capacity and Design for Shear (3.17)	3.4
179. PROJECT: Bond Performance Between Precast UHPC Substrates and Field Cast UHPC Connections	3.4
189. PROJECT: Aerial Infrared Scanning of Bridge Decks for Detecting and Mapping Delamination	3.4
194. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase V	3.4
229. PROJECT: 2290 Bond Behavior of Epoxy Coated Reinforcement Bars in Non-Proprietary UHPC	3.4
251. PROJECT: Investigate Live Load Distribution and Stability of Prestressed Concrete Girders During Construction	3.4
278. PROJECT: Developing Deterioration Curves for Bridge Elements	3.4
302. PROJECT: Low-Cement Concrete Mixture for Bridge Decks and Rails	3.4
325. PROJECT: Post-Fire Damage Inspection of Concrete Structures Phase II – Experimental Phase	3.4
337. PROJECT: Data-Driven Decision-Making Framework for Inspection of Bridge Decks	3.4
362. PROJECT: Testing and evaluation of energy absorbing panels for overheight collision impact protection	3.4
388. PROJECT: Feasibility of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Use in Highway Bridges in Montana: Implementation	3.4

Project Number (from the original list) and Name	Ave Rank
394. PROJECT: Improvement of Approach Smoothness on Integral Abutment Bridges	3.4
463. PROJECT: Residual Capacity of Precast Prestressed Concrete (PPC) Deck Beams with Transverse Cracks	3.4
528. PROJECT: Impacts of Magnesium Chloride Deicer on the Durability of Nanosilica-Modified HVFA Concrete	3.4
555. PROJECT: Development of Deterioration Curves for Bridge Elements in Montana	3.4
601. PROJECT: Application of Methacrylate Polymers for Seismic ABC Connections	3.4
649. PROJECT: Bridge Column Footing Performance and Seismic Retrofit Evaluation Considering Soil-structure Interaction	3.4
650. PROJECT: Synthesis of Information Related to Highway Practices. Topic 51-13. Load Rating of Bridges and Culverts with Missing or Incomplete As-Built Information	3.4
668. PROJECT: Field Implementation and Monitoring of an Ultra-High Performance Concrete Bridge Deck Overlay	3.4
693. PROJECT: Bridge Load Posting Based on Load Testing	3.4
696. PROJECT: Simple for Dead Continuous for Live (SDCL) Steel Girder Bridges with UHPC and GFRP	3.4
714. PROJECT: Cost-Effective Strategies for Retrofitting Culverts with Glass Fiber Reinforced Polymer	3.4
732. PROJECT: Development of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Iowa Bridges TR-773	3.4
767. PROJECT: Development of Non-Proprietary UHPC Mix (University of Oklahoma)	3.4
769. PROJECT: Development of Non-Proprietary UHPC Mix – Application to Deck Panel Joints (University of Nevada, Reno)	3.4
829. PROJECT: Sustainability and Resiliency of Concrete Rapid Repairs Utilizing Advanced Cementitious Materials – Freeze/Thaw Loads	3.4
6. PROJECT: Super-Elastic Copper-Based and Iron-Based Shape Memory Alloys and Engineered Cementitious Composites for Extreme Events Resiliency	3.2
26. PROJECT: NJDOT Corrosion Study on Steel Structural Members	3.2
27. PROJECT: Guide for 3D Model Viewers for Construction Inspection	3.2
31. PROJECT: Development of Deterioration Curves for Ohio Bridges	3.2
59. PROJECT: SPR-4730: Widening Reinforced Concrete Elements using Chemical Anchoring Systems (Post-installed Rebar Systems)	3.2
75. PROJECT: Synthesis of Information Related to Highway Practices. Topic 54-11. Quality Control Checks for Bridge and Structure Analysis Models	3.2
109. PROJECT: Entire Interior Culvert Lining with Engineered Cementitious Composites	3.2
115. PROJECT: QA/QC Guidelines on Drone-based Remote Sensing for Bridge Element Inspection (IM-4)	3.2
124. PROJECT: Modeling of Stainless-steel Reinforcement Corrosion	3.2
155. PROJECT: Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials	3.2
166. PROJECT: TRC2203 - Low-Shrinkage Concrete Mixtures for Arkansas	3.2
176. PROJECT: CT Girder with FRP Shear Studs – Strength & Fatigue Testing	3.2

Project Number (from the original list) and Name	Ave Rank
180. PROJECT: Connecting the DOTs: Implementing ShakeCast Across Multiple State Departments of Transportation for Rapid Post-Earthquake Response	3.2
181. PROJECT: Development of Non-proprietary Prefabricated Solutions for Concrete Barrier Systems for Accelerated Bridge Construction	3.2
196. PROJECT: Fiber Reinforced Concrete (FRC) Beam End Repairs for Corroded Steel Beam Ends	3.2
206. PROJECT: Synthesis of Galvanized Steel Reinforcement Corrosion Performance	3.2
213. PROJECT: CT Bridge Girder Sections with Precast Decks and FRP Girder-Deck Shear Connectors (3.16)	3.2
215. PROJECT: Protecting Critical Civil Infrastructure Against Impact from Commercial Vehicles – Phase 3, A Systems Based Approach Including Fire	3.2
249. PROJECT: Re-Examine Minimum Reinforcement Requirements for Shear Design	3.2
267. PROJECT: Increasing Bridge Durability and Service Life with LIDAR Enhanced Unmanned Aerial Systems (UAS)	3.2
285. PROJECT: Implementation of UHPC Technology into the New England Construction Industry (2.14)	3.2
301. PROJECT: Production of Cast-in-Place UHPC for Bridge Applications	3.2
322. PROJECT: Sustainable nHPC Mixtures for Durable Overlay of Concrete Bridge Decks in Cold Regions: Proof of Concept	3.2
326. PROJECT: Revised Load Rating Procedures for Deteriorated Prestressed Concrete Beams	3.2
354. PROJECT: Life-Cycle Cost Analysis of Ultra High-Performance Concrete (UHPC) in Retrofitting Techniques For ABC Project	3.2
403. PROJECT: Analysis of ABC Bridge Column-to-Footing Joints with Recessed Splice Sleeve Connectors	3.2
474. PROJECT: Field retrofit and testing of a corroded corrugated metal culvert using Glass Fiber Reinforced Polymers	3.2
507. PROJECT: Use of Sand Lightweight Concrete and All Lightweight Concrete to Improve Properties	3.2
533. PROJECT: Post-Earthquake Serviceability of RC Bridge Bents Using Visual Inspection	3.2
539. PROJECT: Quantitative Assessment of Soil-Structure Interaction (SSI) Effects on Seismic Performance of Bridges with ABC Connections	3.2
558. PROJECT: Concrete Systems for a 100-Year Design Life (2.2)	3.2
563. PROJECT: Assessment, Repair and Replacement of Bridges Subjected to Fire	3.2
616. PROJECT: External Pocket and Socket Connections for the Seismic Design of Alaska Bridges	3.2
646. PROJECT: 2287 Evaluation of the Expected Life and Recoating of Silane Water Repellant Treatments on Bridge Decks	3.2
740. PROJECT: Optimized performance of UHPC bridge joints and overlays	3.2
745. PROJECT: Improved Methods to Assess Corrosion Damage in Prestressed Concrete Beams	3.2
747. PROJECT: Protecting Critical Civil Infrastructure Against Impact from Commercial Vehicles – Phase I, Year 2	3.2
766. PROJECT: Performance of Existing ABC Projects – Inspection Case Studies (University of Nevada, Reno)	3.2
774. PROJECT: Development of ABC Course Module – Seismic Connections	3.2

Project Number (from the original list) and Name	Ave Rank
842. PROJECT: TRC1903 - Investigating Concrete Deck Cracking in Continuous Steel Bridges	3.2
854. PROJECT: Design Optimization and Monitoring of Joint-less Integral and Semi-Integral Abutment Bridges in Nebraska	3.2
14. PROJECT: FSBs with Stainless Steel Strands and GFRP Shear Reinforcement	3.0
40. PROJECT: SPR-4733: Steel Bridge Inspection, Assessment, Repair, and Management under FIRE	3.0
41. PROJECT: Seismic Behavior of Hider Wing-Walls	3.0
84. PROJECT: Current State of Simulated Deck Samples Cast with Corrosion Resistant Alloys (>16 years)	3.0
96. PROJECT: SPR-4729: Evaluation of the Accuracy of Non-Destructive Testing (NDT) Methods for the Condition Assessment of Bridge Decks and Integration of NDT into the Asset Management Program	3.0
98. PROJECT: UAS-Assisted Inspection of Bridges for Corrosion Effects	3.0
123. PROJECT: Prediction and Prevention of Bridge Performance Degradation due to Corrosion, Material Loss, and Microstructural Changes (C21.2022)	3.0
136. PROJECT: Development of P-Y Curves for Analysis of Laterally Loaded Piles in Montana	3.0
154. PROJECT: Accelerated Sulfate Attack Testing for Concrete	3.0
164. PROJECT: Pragmatic Precast/Prestressed Girder Acceptance Criteria	3.0
191. PROJECT: Design of Anchors for Rapid and Durable Strengthening of Bridges with Externally Bonded Carbon Fiber Reinforced Polymer Composites—Phase 2	3.0
208. PROJECT: ADOT Strut-and-Tie Modeling Design Guidance	3.0
234. PROJECT: Ultra-High-Performance Concrete (UHPC) Used as a High Friction Surface Treatment (HFST) on Pavements and Bridges	3.0
237. PROJECT: Numerical Simulation of Strengthening of Bridge Decks with Partial-Depth Precast Deck Panels	3.0
276. PROJECT: Strut-and-Tie Design and Evaluation of Reinforced Concrete Bridge Bent Caps	3.0
279. PROJECT: Development of Design Recommendations for Non-Contact, Hooked Bar Lap Splices for Large Reinforcing Bars	3.0
284. PROJECT: Enhancing the Durability of Bridge Decks by Incorporating Microencapsulated Phase Change Materials (PCMs) in Concrete (2.16)	3.0
298. PROJECT: Truck Platooning Effects on Girder Bridges, Phase II	3.0
304. PROJECT: Support for AASHTO Committees and Councils. AASHTO Committee on Bridges and Structures Strategic Plan, Operating Guidelines, and Research Roadmap Development	3.0
308. PROJECT: Seismic Performance and Fragility of Retrofitted Reinforced Concrete Bridge Columns to Long-Duration Earthquakes	3.0
312. PROJECT: Repairable Precast Bridge Bents for Extreme Events	3.0
327. PROJECT: Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement	3.0
331. PROJECT: Applicability of Approximate Methods of Analysis for Skewed Straight Steel I-Girder Bridges	3.0

Project Number (from the original list) and Name	Ave Rank
332. PROJECT: Seismic Behavior of High Strength Reinforcing Steel at Low Temperatures	3.0
336. PROJECT: Repairing Concrete Structures Using Near-Surface Mounted Composites with Inorganic Resins under Simulated Multihazard Damage	3.0
340. PROJECT: 2313 Design and Monitoring of Non-Proprietary UHPC Joints of Precast Elements	3.0
341. PROJECT: RES2021-14: Seismic Monitoring for Asset Management and Prioritization of Transportation Infrastructure	3.0
343. PROJECT: Investigation of the Benefit of Using a Novel Corrosion Resistant Steel in New and Existing Steel Bridges in Pennsylvania	3.0
353. PROJECT: Exploring Fiber-Reinforced Polymer Concrete for Accelerated Bridge Construction Applications	3.0
364. PROJECT: UHPC Mixture Design for Accelerated Bridge Construction	3.0
390. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase IV	3.0
407. PROJECT: Repair or Strengthening of Bridge Decks with Partial-Depth Precast Deck Panels	3.0
458. PROJECT: Investigation and Assessment of Effective Patching Materials for Concrete Bridge Decks	3.0
505. PROJECT: Impact of Truck Platooning on Loading of Bridges in Oregon	3.0
553. PROJECT: LRFR Bridge Load Rating	3.0
621. PROJECT: Sensor-assisted Condition Evaluation of Steel and Prestressed Concrete Girder Bridges Subjected to Fire – Phase III	3.0
623. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase III	3.0
640. PROJECT: Post-Fire Damage Inspection of Concrete Structures	3.0
654. PROJECT: Research for AASHTO Standing Committee on Highways. Task 428. Update of the 2012 AASHTO Guide Specification for Design of Bonded FRP Systems for Repair	3.0
655. PROJECT: Research for AASHTO Standing Committee on Highways. Update of the 2012 AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements	3.0
667. PROJECT: Development of Low-Cost Multifunctional Materials for Near-Surface-Mounted (NSM) Strengthening of RC Bridge Beams and Columns	3.0
703. PROJECT: Reliability of Nondestructive Evaluation Methods for Bridge Decks	3.0
712. PROJECT: Optimization of Advanced Cementitious Material for Bridge Deck Overlays and Upgrade, Including Shotcrete	3.0
731. PROJECT: Applications of Elastomeric Polymers for Accelerated Bridge Construction and Retrofit	3.0
768. PROJECT: Development of Non-Proprietary UHPC Mix (Iowa State University)	3.0
775. PROJECT: Performance of Existing ABC Projects – Inspection Case Studies (University of Washington)	3.0
796. PROJECT: RES2019-17: Concrete Bridge Deck Deterioration Assessment Using Ground Penetrating Radar	3.0
808. PROJECT: Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking	3.0
813. PROJECT: Sustainable, Rapid Repair Using Advanced Cementitious Materials	3.0

Project Number (from the original list) and Name	Ave Rank
845. PROJECT: Concrete-Filled Steel Tube to Concrete Pile Cap Connections – Further Evaluation/Improvement of Analysis/Design Methodologies	3.0
21. PROJECT: Bridge Element Deterioration for Midwest States	2.8
23. PROJECT: GFRP Barrier Testing Evaluation and Repair Strategies	2.8
30. PROJECT: Development of Criteria to Assess the Effects of Pack-out Corrosion in Built-up Steel Members	2.8
72. PROJECT: Calibrating Ground Response Analyses beneath an Instrumented Bridge Using the I-15 Borehole Array and Ground Motions from the Magna Earthquake	2.8
92. PROJECT: Rapid Damage Assessment in Infrastructure Systems using Vibration Measurements within a Machine Learning Framework	2.8
106. PROJECT: RES2023-04: Best Practices for Bridges with Pipe Piles	2.8
118. PROJECT: A Risk-Based Framework for Optimizing Inspection Planning of Utah Culverts	2.8
125. PROJECT: NEXTGEN Concrete - Tests of the Future: Shrinkage	2.8
133. PROJECT: Evaluation of Embedded Pile Resistance of Scour Critical Bridges	2.8
150. PROJECT: Bridge Inspection Training and Enhanced Operations using Augmented Reality	2.8
178. PROJECT: Composite Tub Girder Live Load Testing and Shear Force Distribution	2.8
185. PROJECT: Over-height vehicle impact with bridge girders having different boundary conditions	2.8
216. PROJECT: SPR-4632: Steel Bridge Coating Evaluation and Rating Criteria	2.8
226. PROJECT: Repair of Bridge Deck Fascias	2.8
245. PROJECT: Influence of Revising CFCC Guaranteed Strength on Performance of CFCC Prestressed Highway Bridge Beams Subjected to Various Environmental Conditions	2.8
247. PROJECT: Development of a Continuous for Live Load Prefabricated Steel Accelerated Bridge Construction (ABC) Unit for Texas Bridges	2.8
248. PROJECT: Determine Service and Ultimate Behavior for Bent to Column Joints in TxDOT Substructures	2.8
255. PROJECT: Development of Simplified Factors for Lateral Distribution of Loads of Non-Standard Gauge (NSG) Axles	2.8
262. PROJECT: Environmentally Sustainable Accelerated Partial Bridge Deck Concrete Removal Methods Analysis	2.8
266. PROJECT: SPR-4634: Investigating Consistency among Bridge Inspectors Using Simulated Virtual Reality Testbed	2.8
271. PROJECT: Development of Adjustment Factors and Bridge Load Ratings through Statistical Analyses of the NBI Database	2.8
272. PROJECT: Remediating Disproportionate Approach Slab Settlements in Kansas Integral Bridges	2.8
307. PROJECT: LRFR Methodology for Missouri Bridges	2.8
314. PROJECT: Durability of Low Carbon Concrete Mixtures	2.8
315. PROJECT: Proposed AASHTO Guidelines for Applications of Unmanned Aerial Systems Technologies for Element-Level Bridge Inspection	2.8

Project Number (from the original list) and Name	Ave Rank
316. PROJECT: Reducing Shrinkage Cracking in Bridge Decks Using the Single and Double-Ring Test Methods	2.8
346. PROJECT: Design Guidance for UHPC Connections of Precast Girders Made Continuous for Live Load	2.8
363. PROJECT: Full scale crash testing to validate FE simulations of heavy vehicles impact	2.8
373. PROJECT: Robust Methods for UHPC Early-Strength Determination and Quality Control for ABC	2.8
452. PROJECT: Develop Closure Joint Materials Specification and Evaluate Performance for Side-By-Side Accelerated Bridge Construction (ABC) Superstructure Systems	2.8
478. PROJECT: Multifunctional corrosion control system as a sustainable approach for reinforced concrete elements	2.8
482. PROJECT: Efficient, Low-cost Bridge Cracking Detection and Quantification Using Deep-learning and UAV Images	2.8
487. PROJECT: Evaluation of Alternative Sources of Supplementary Cementitious Materials (SCMs) for Concrete Materials in Transportation Infrastructure	2.8
503. PROJECT: Identifying Critical Waterway Infrastructure and Managing Risk Associated with Natural Disasters	2.8
523. PROJECT: Robust Wireless Skin Sensor Networks for Long-term Fatigue Crack Monitoring of Bridges	2.8
541. PROJECT: FRP-Concrete Hybrid Composite Girder Systems: Web Shear Strength and Design Guide Development	2.8
564. PROJECT: Alternative Technical Concepts for Contract Delivery Methods in Accelerated Bridge Construction	2.8
568. PROJECT: Investigation into the Contributing Factors to the Corrosion of Steel Reinforced Concrete Structures at Elevations Greater than 12 Feet Above the mean High Water Line	2.8
608. PROJECT: Service Life Design Guidance For UHPC Link Slabs	2.8
645. PROJECT: Real-time Bridge Scour Monitoring and Evaluation at Selected sited in Idaho, Water Years 2020-2022	2.8
674. PROJECT: Fiber Reinforcement for Latex Modified Concrete Overlays	2.8
700. PROJECT: Performance and Improvement of Texas Poor Boy Continuous Bridge Deck Details	2.8
764. PROJECT: Performance of Existing ABC Projects: Inspection Case Studies (University of Oklahoma)	2.8
765. PROJECT: Performance of Existing ABC Projects – Inspection Case Studies (Iowa State University)	2.8
776. PROJECT: Available ABC Bridge Systems for Short Span Bridges – Course Module	2.8
777. PROJECT: Condition Assessment of Corroded Prestressed Concrete Bridge Girders (C3.2018)	2.8
810. PROJECT: Field Evaluation of Reinforced Concrete Repairs using Hydro-Demolition, Galvanic Cathodic Protection or Impressed Current Cathodic Protection	2.8
812. PROJECT: SPR-2313: Repair of Steel Beam/Girder Ends with Ultra High-Strength Concrete, Phase III: Implementation and Training	2.8
828. PROJECT: Utilization of UHPC Bridge Superstructures in Texas	2.8
69. PROJECT: Building Information Modeling (BIM) for Infrastructure	2.6

Project Number (from the original list) and Name	Ave Rank
70. PROJECT: Numerical Analysis of ABC Hybrid Bridge Bents Constructed with Hybrid Reinforcement	2.6
81. PROJECT: 2317 Effectiveness of Magnesuim-Alumino-Liquid-Phosphate-Based concrete as a Repair Material (MALP)	2.6
82. PROJECT: 2316 Solving the Riddle of End Regions - and Holistically Address the Performance of PC Girder Bridges Including Design, Sustainability and Rating	2.6
83. PROJECT: Predicting Wildlife Use of Existing Highway Bridges and Culverts	2.6
112. PROJECT: Thinking Inside the Box (Culvert): Developing a Low-Cost, Easy-to-Install Retrofit Prototype for Fish Passage	2.6
116. PROJECT: Mixed Reality for Beyond Visual Line-of-Sight Bridge Inspection Using Robot-Assisted Nondestructive Evaluation (IM-5)	2.6
120. PROJECT: Bond Performance of Post-tensioning Tendons with Corrosion Inhibitor	2.6
134. PROJECT: Protective Performance of Externally-Bonded, Nano-Modified FRP for Concrete	2.6
158. PROJECT: Evaluation of Alternative Sources of Supplementary Cementitious Materials (SCMs) for Engineered Cementitious Composites in Transportation Infrastructure	2.6
175. PROJECT: An Artificial intelligence (AI) Based Overheight Vehicle Warning System for Bridges	2.6
184. PROJECT: Impact Test of GFRP Reinforced Concrete Bridge Barriers	2.6
195. PROJECT: Real-time Flood Forecasting for River Crossings – Phase V	2.6
230. PROJECT: A Direct Design Method of Hybrid High Strength Steel Web Tapered Members	2.6
233. PROJECT: Damage Modeling, Monitoring, and Assessment of Bridge Scour and Water Borne Debris Effect for Enhanced Structural Life (C19.2020)	2.6
236. PROJECT: Guide for Preventing and Mitigating the Risk of Bridge and Tunnel Strikes by Motor Vehicles	2.6
239. PROJECT: Remote Sensing of Transportation Assets Using Drones and Artificial Intelligence	2.6
261. PROJECT: Impacts of Vehicle Fires on Polymer Concrete Bridge Deck Overlays	2.6
264. PROJECT: A Study of Re-Decking Prestressed Girders Phase 1: State of Practice and Preliminary Analysis Recommendations	2.6
300. PROJECT: Accelerated Bridge Construction (ABC) Decision Tool	2.6
321. PROJECT: Low-Carbon Concrete Pilot Program	2.6
329. PROJECT: Fatigue Characterization of Galvanized Welded Connections	2.6
350. PROJECT: Truck Platooning Impacts on Bridges, Phase II: Structural Serviceability	2.6
380. PROJECT: Design and Numerical Evaluation of GFRP Reinforcement for Concrete Bridge Railing	2.6
401. PROJECT: Resilience-Based Recovery Planning of Transportation Network Following Earthquakes	2.6
408. PROJECT: Investigating Thermal Imaging Technologies and Unmanned Aerial Vehicles to Improve Bridge Inspections	2.6
435. PROJECT: Innovative Short-Span Concrete Bridge Superstructures	2.6

Project Number (from the original list) and Name	Ave Rank
436. PROJECT: Development of a Standardized Test Method for Durability of Ultra-High Performance Concrete	2.6
461. PROJECT: SPR-4527: Shear and Bearing Capacity of Corroded Steel Beam Bridges and Effects on Load Rating	2.6
473. PROJECT: Bridge Cracks Monitoring: Detection, Measurement, and Comparison using Augmented Reality	2.6
486. PROJECT: Development of Novel Ultra-High Performance Engineered Cementitious Composites (UHP-ECC) for Durable and Resilient Transportation Infrastructure	2.6
488. PROJECT: Bridge Load Posting Prediction	2.6
502. PROJECT: Assessment and Optimization of Double Ct Bridge Girder Sections with Longitudinal Precast Decks (3.10)	2.6
521. PROJECT: Development of Optimized Decked Bulb-Tee Girders for Alaska	2.6
527. PROJECT: Develop an Innovative Self-Healing Concrete Technology for Bridge Deck Life Extension	2.6
565. PROJECT: Curved Integral Abutment Bridge Design	2.6
589. PROJECT: Health Inspection of Concrete Pavement and Bridge Members Exposed to Freeze-Thaw Service Environments (SN-7)	2.6
610. PROJECT: Design Guidelines for ABC Column-to-Drilled-Shaft Foundation Connections in High Seismic Zones	2.6
614. PROJECT: The Effects of Surface Condition and Long-Term Environmental Exposure on the Bond Between Carbon Fiber-Reinforced Polymers and Steel	2.6
619. PROJECT: Development of Knowledge in the Application of Strut-and-Tie Modeling	2.6
626. PROJECT: Develop NextGen Texas Bridge Decks	2.6
705. PROJECT: Field Live Load Testing and Advanced Analysis of Concrete T-Beam Bridges to Extend Service Life (1.1)	2.6
706. PROJECT: Developing and refining fragility curves used for ShakeCast and implementation of ShakeCast across multiple states	2.6
742. PROJECT: Testing, Monitoring and Analysis of FRP Girder Bridge with Concrete Deck (3.4)	2.6
754. PROJECT: Ultra-High-Performance Concrete (UHPC) Use in Florida Structural Applications	2.6
772. PROJECT: Synthesis of available methods for repair of prestress girder ends	2.6
781. PROJECT: Electromagnetic Detection and Identification of Concrete Cracking in Highway Bridges (1.4)	2.6
782. PROJECT: Repair of Corroded Steel H-Piles Using Performance Material – Phase II (UHPC and FRP Repair Sections)	2.6
785. PROJECT: SMART Shear Keys for Multi-Hazards Mitigation of Diaphragm-Free Girder Bridges – Phase II	2.6
789. PROJECT: Design and Detailing Requirements for Columns under Collision TR-768	2.6
799. PROJECT: Evaluation of Glass Fiber Reinforced Polymers (GFRP) Spirals in Corrosion Resistant Concrete Piles	2.6
852. PROJECT: SPR-4326: Self-healing Cementitious Composites (SHCC) with Ultrahigh Ductility for Pavement and Bridge Construction	2.6
2. PROJECT: Practices to Enhance Resiliency of Existing Culverts	2.4

Project Number (from the original list) and Name	Ave Rank
10. PROJECT: Enhancement of AASHTOWare Bridge Management for Florida's Bridge Inspection and Asset Management	2.4
15. PROJECT: Update Bridge Construction Requirements	2.4
28. PROJECT: Evaluation of Ultra-High-Performance Concrete (UHPC) Pile Splices	2.4
29. PROJECT: Center for the Aging Infrastructure: Steel Bridge Research, Inspection, Training and Education Engineering Center - SBRITE (Continuation)	2.4
38. PROJECT: Effect of Spacing on Axial Resistance of Auger Cast Pile Foundations	2.4
71. PROJECT: Numerical Modeling and Parametric Analysis of Grouted Coupler Connections under Varying Impact Loading Conditions	2.4
79. PROJECT: Enhanced Bridge Cost Estimating	2.4
90. PROJECT: Intermediate Bents-Calculation of Restraint Factor	2.4
102. PROJECT: Evaluation of Indented Prestressing Wires for KDOT Bridge Members	2.4
117. PROJECT: Develop Element Level Bridge Performance Measures and Targets	2.4
142. PROJECT: Field Evaluation of Wireless Ultrasonic Thickness Measurement with Steel Bridge Members.	2.4
193. PROJECT: Development of new design guidelines for protection against erosion at bridge abutments - Phase V	2.4
197. PROJECT: Condition Dependent Performance Based Seismic Design Phase I	2.4
211. PROJECT: Transition of Allowable Stress Rating to Load and Resistance Factor Rating for Timber Bridges	2.4
217. PROJECT: Dissimilar Metal Welds Between ASTM A709 Grade 50CR and Other Bridge Steels	2.4
228. PROJECT: 2291 A Fatigue Assessment Framework for Steel Bridges using Fiber Optic Sensors and Machine Learning	2.4
275. PROJECT: Developing Workflow, Implementation Tools, and Guidance for Efficient UAV-enabled Bridge Inspection	2.4
280. PROJECT: SPR-4631: Evaluation of the Potential Benefits of Implementing the AASHTO Guide Specifications for the Analysis and Identification of Fracture Critical Members and System Redundant Members	2.4
313. PROJECT: Drone-Based Measurements for Bridge Field Testing – Development Phase	2.4
374. PROJECT: Towards Autonomous UAV-Based Dynamic and Seismic Response Monitoring of Bridges	2.4
377. PROJECT: TRC2106 - Applying UAS LiDAR for Developing Small Project Terrain Models	2.4
395. PROJECT: SPR-4526: Predictive Analytics for Quantifying the Long-Term Cost of Defects During Bridge Construction	2.4
437. PROJECT: AASHTO Design Guidance for UHPC Structures	2.4
441. PROJECT: Risk based framework for culvert evaluation/load rating	2.4
460. PROJECT: FRP-Concrete Hybrid Composite Girder Systems: Web Shear Strength and Design Guide Development (3.14)	2.4
464. PROJECT: Phase 2: Computationally Informed Methodologies for Capturing the Effect of Intervening Structures during Truck Impact Events	2.4

Project Number (from the original list) and Name	Ave Rank
512. PROJECT: Automated Bridge Inspection using Digital Image Correlation Phase III – Examination Alternative Vision-based Methods and Deployment Mechanisms for Field Implementation	2.4
548. PROJECT: UHPC connection for SDCL steel bridge system	2.4
574. PROJECT: Behavior of Composite-Strengthened Concrete Bridge Members under Multi-Hazard Loadings	2.4
617. PROJECT: SPR-4431: A New Approach to Accelerated Fabrication of Steel Bridges: Design, Optimization, and Demonstration	2.4
629. PROJECT: Evaluation of Corrosion Prevention and Mitigation Approaches Used On Texas Bridges	2.4
636. PROJECT: Advanced Non-Destructive Bridge Deck Condition Assessment	2.4
664. PROJECT: Design and Construction Specifications for Bonded and Unbonded Post-Tensioned Concrete Bridge Elements	2.4
681. PROJECT: SPR-4444: Improved Live Load Lateral Distribution Factors for use in Load Rating of Older Continuous and T-Beam Reinforced Concrete Bridges	2.4
709. PROJECT: Durability Evaluation of Carbon Fiber Composite Strands in Highway Bridges (2.10)	2.4
737. PROJECT: Performance of Existing ABC Projects: Inspection Case Studies (Florida International University)	2.4
786. PROJECT: Sensor-assisted Condition Evaluation of Steel and Prestressed Concrete Girder Bridges Subjected to Fire – Phase II	2.4
787. PROJECT: 3D Printed FRP-Concrete-Steel Composite Hollow Core Bridge Column	2.4
831. PROJECT: SPR-4320: Implementation of Epoxy Injection of Concrete Overlaid Bridge Decks	2.4
11. PROJECT: Development and Evaluation of Box-Beam Barrier Configuration for Shielding Fixed Objects and Bridge Ends in Medians	2.2
13. PROJECT: Guidelines for the Application of Ground Modification Methods for Highway Structures	2.2
60. PROJECT: Remote Bridge Health Monitoring for Scouring Using Cost-Efficient Sensing Technology	2.2
105. PROJECT: MASH TL-4 Engineering Analyses and Detailing of 36-inch and 42-inch High Median Barriers for LADOTD	2.2
113. PROJECT: Air-Coupled GPR and HD Imaging for High-Speed Bridge Deck Evaluation	2.2
119. PROJECT: Half-Round Bearing Stiffeners for Skewed Steel I-Girders	2.2
126. PROJECT: GBeam Bridge Girder Pultrusion: Section Design and Optimization (3.21)	2.2
137. PROJECT: Feasibility of 3D Printing Applications for Highway Infrastructure Construction and Maintenance - Phase II	2.2
149. PROJECT: Monotonic and cyclic behavior of high strength reinforcing steel (HSRS) after high temperature exposure	2.2
252. PROJECT: Investigate the Strength of Struts Crossing Cold Joints	2.2
265. PROJECT: Economical Impact of Full Closure for Accelerated Bridge Construction and Conventional Staged Construction	2.2
270. PROJECT: A Bridge Digital Twin for Enhancing Transportation Resilience and Asset Management	2.2
273. PROJECT: Comparative Analysis of 3D Printed Bridge Construction in Louisiana	2.2

Project Number (from the original list) and Name	Ave Rank
296. PROJECT: Utilizing a Particle Packing Approach for an Illinois-specific, Nonproprietary, Low-Shrinkage UHPC	2.2
303. PROJECT: Quantifying Benefits of Bridge Maintenance	2.2
338. PROJECT: Reducing Shrinkage in Concrete Bridge Decks using Single and Double Ring Test Methods	2.2
342. PROJECT: Field Application of a High-Power Density Electromagnetic Energy Harvester to Power Wireless Sensors in Transportation Infrastructures	2.2
345. PROJECT: Project Management Plans to Support Successful Delivery of Accelerated Bridge Construction Projects	2.2
370. PROJECT: Interfacial Shear Transfer of Reinforced Concrete with High-Strength Materials	2.2
416. PROJECT: Strength and Serviceability of Damaged Steel Girders	2.2
421. PROJECT: A Guide for Incorporating Maintenance Costs into a Transportation Asset Management Plan	2.2
462. PROJECT: MASH Railing Load Requirements for Bridge Deck Overhang	2.2
467. PROJECT: Guidelines for Response Planning, Assessment, and Rapid Restoration of Service of Bridges in Extreme Events	2.2
471. PROJECT: Resilient 3D-Printed Infrastructure with Engineered Cementitious Composites (ECC)	2.2
490. PROJECT: SPR-4516: Development of Protocols for Reuse Assessment of Existing Foundations in Bridge Rehabilitation and Replacement Projects	2.2
513. PROJECT: Load Rating Assessment of Three Slab-Span Bridges over Shingle Creek	2.2
543. PROJECT: Strength and Constructability of a Double Composite Steel Box Girder	2.2
551. PROJECT: SMART Shear Keys for Multi-Hazards Mitigation of Diaphragm-Free Girder Bridges - Phase III	2.2
584. PROJECT: Unmanned Aerial Vehicles for Inspection of Tack Coats and Ancillary Highway Structures	2.2
586. PROJECT: Bridge Weigh in Motion For Simultaneous Multiple Vehicles	2.2
587. PROJECT: Smart Mobile Platform for Model Updating and Life Cycle Assessment of Bridges	2.2
602. PROJECT: Work Zone Safety Analysis, Investigating Benefits from Accelerated Bridge Construction (ABC) on Roadway Safety	2.2
604. PROJECT: Prefabricated Barrier System Utilizing UHPC Connections	2.2
609. PROJECT: Economic Pier-to-Pile Connections for Permanently Cased Shaft (CFST) Piles	2.2
618. PROJECT: Use of Larger Diameter Shear Studs for Composite Steel Bridges	2.2
660. PROJECT: Assessment of Micropile-Supported Integral Abutment Bridges (3.11)	2.2
689. PROJECT: Use of Rapid Setting Hydraulic Cement (RSHC) for Structural Applications	2.2
725. PROJECT: Crash Testing of a Precast Concrete Barrier TPF-5(367)	2.2
770. PROJECT: Development of ABC Course Module: Design of Link Slabs	2.2
791. PROJECT: Rapid Repair of Column to Footing Phase 2	2.2

Project Number (from the original list) and Name	Ave Rank
821. PROJECT: TRC1901 - Spatial Analysis of Benefits of Site Specific Ground Motion Response Analysis	2.2
824. PROJECT: Exploration of Ultrasound for the Evaluation and Preservation of Structures TR-757	2.2
832. PROJECT: Out-of-Plane Seismic Response of Pocket Connections for Cast-in-Place and Precast Construction (NDOT 494-18-803)	2.2
844. PROJECT: Proposed AASHTO Guidelines for Adjacent Precast Concrete Box Beam Bridge Systems	2.2
49. PROJECT: SPR-4732: Development of Guidelines for Use and Design of Deep Foundations for Three-Sided Structures	2.0
50. PROJECT: SPR-4715: Study on the Permissible Depth of Utilities under the MSE Walls and Means and Methods of Protecting the MSE Walls when the Permissible Depth cannot be Provided	2.0
63. PROJECT: Quality Manual for Steel Bridge Fabrication	2.0
91. PROJECT: Calibration of Bridge Performance Models Using Element Data	2.0
121. PROJECT: Effects of Composition and Temperature Control Measures on Mass Concrete Durability	2.0
161. PROJECT: Determination of Bridge Element Weights based on Data-driven Models	2.0
204. PROJECT: Non-Contact 3-Component (3C) Displacement Measurements with a Dual-Stereo Vision Enabled Uncrewed Aerial System (UAS)	2.0
214. PROJECT: Investigation and Development of a MASH Test Level 6, Cost-Effective Barrier System for Containing Heavy Tractor Tank-Trailer Vehicles and Mitigating Catastrophic Crash Events – Phase V	2.0
222. PROJECT: Instrumentation to Aid in Steel Bridge Fabrication	2.0
231. PROJECT: Wireless Joint Monitoring System (w-JMS) for Safety of Highway Bridges (1.16)	2.0
250. PROJECT: Develop Deck and Overhang Design Guidelines for Sound Walls and Other Heavy Loads	2.0
257. PROJECT: SPR-4635: New Repair Strategies for Life-Cycle Extension of Corroded Steel Girder Bridges	2.0
268. PROJECT: Integrate infrastructure performance monitoring using automatic crack evaluation system and convolutional neural network	2.0
269. PROJECT: Evaluation of Fresh and Hardened Properties of 3D-Printed Engineered Cementitious Composites (ECC) Designed for Sustainable and Resilient Infrastructure Systems	2.0
294. PROJECT: Developing Guidelines for Evaluating Pressure on Existing Culverts under New Embankments with Buried Lightweight Materials when Highway Widening	2.0
311. PROJECT: Efficacy and Safety of Combining Heat Induction and Laser Ablation for the Removal of Potentially Hazardous Bridge Coatings	2.0
349. PROJECT: Use of All Lightweight Concrete in Conjunction with UHPC Connection for Prefabricated Barrier System	2.0
358. PROJECT: Peak Temperature Determination of Drilled Shafts Excluded from Mass Concrete Consideration in Current Specifications	2.0
360. PROJECT: SPR-4546: Implementation Study: Continuous, Wireless Data Collection and Monitoring of the Sagamore Parkway Bridge	2.0
396. PROJECT: TRC2104 - Maintenance Guidelines for Mechanically Stabilized Earth (MSE) Walls	2.0
412. PROJECT: Load path redundancy as a protection measure - Phase 1	2.0

Project Number (from the original list) and Name	Ave Rank
419. PROJECT: Quality Assurance Guidelines for Bridge Construction	2.0
438. PROJECT: Multi-Hazard Bridge Design--Risk Evaluation and Risk Management through Load and Resistance Factor Design (LRFD) Calibration	2.0
439. PROJECT: Vulnerability of critical bridge components accessible by Unmanned Aerial Systems (UAS) threats	2.0
445. PROJECT: Fire damage detection and evaluation	2.0
451. PROJECT: Development of New Design Guidelines for Protection Against Erosion at Bridge Abutments - Phase IV	2.0
459. PROJECT: Stainless Steel Strands for Prestressed Concrete Bridge Elements	2.0
465. PROJECT: SPR-4432: Culvert Inspection Frequency Determination – Guidelines for INDOT	2.0
481. PROJECT: Deep reinforcement learning-based prioritization for rapid post disaster recovery of transportation infrastructure systems	2.0
484. PROJECT: Developing Notification and Enforcement Systems to Communicate and Administer Bridge Load Postings	2.0
511. PROJECT: Effects of Composition and Temperature Control Measures on Mass Concrete Durability	2.0
544. PROJECT: Assessment of Structural Steel Coating Applications	2.0
549. PROJECT: Lidar-Based Vibration Monitoring for Assessing Safety of Damaged Bridges	2.0
561. PROJECT: Simulation Training to Work With Bridge Inspection Robots (WD-3)	2.0
566. PROJECT: Evaluate Effects from Shored Construction on Steel Composite Bridges	2.0
577. PROJECT: Evaluation of Liquefaction Induced Lateral Spread from Recent Alaska Earthquakes	2.0
595. PROJECT: Augmented Bridge Inspection with Augmented Reality and Haptics-based Aerial Manipulation (AS-7)	2.0
598. PROJECT: A Field Deployable Wall-Climbing Robot for Bridge Inspection using Vision and Impact Sounding Techniques (AS-6)	2.0
647. PROJECT: Analytical and Testing Methods for Rating Longitudinal Laminated Timber Slab Bridges	2.0
656. PROJECT: Develop NextScour: Hydraulics Design Tools	2.0
663. PROJECT: SPR-4429: Use of LRFR Methodology for Load Rating of INDOT Steel Bridges	2.0
673. PROJECT: Developing a Safe and Cost-Effective Flight Control Methodology for a UAV-Enabled Bridge Inspection	2.0
684. PROJECT: Corrosion Resistant Steel Bridges on Virginia's Eastern Shore	2.0
685. PROJECT: Evaluation of Seamless Bridges	2.0
719. PROJECT: Effectiveness of Epoxy Chip Seals for SD Bridge Decks	2.0
720. PROJECT: Improved Load Rating Procedures for Deteriorated Steel Beam Ends	2.0
734. PROJECT: Late Life Low Cost Deck Overlays TR-775	2.0
741. PROJECT: Bridge Load Rating and Evaluation Using Digital Image Measurements	2.0

Project Number (from the original list) and Name	Ave Rank
755. PROJECT: NCHRP Implementation Support Program. Implementing Products from NCHRP Research on Adhesive Anchor Systems	2.0
794. PROJECT: SPR-4311: Evaluating Reserve Strength of Girder Bridges due to Bridge Rail Load Shedding	2.0
800. PROJECT: Automated Bridge Inspection using Digital Image Correlation Phase II – Application of Digital Image Correlation Techniques for In-Service Inspection Conditions	2.0
802. PROJECT: Real-Time Flood Forecasting for River Crossings – Phase II	2.0
803. PROJECT: Development of New Design Guidelines for Protection Against Erosion at Bridge Abutments and Embankments – Phase II	2.0
822. PROJECT: Impact of Construction Loads on Steel Diaphragm Bridge Design	2.0
841. PROJECT: Sustainable Alternative to Structurally Deficient Bridges	2.0
846. PROJECT: Evaluation of Spatial and Temporal Load Distribution in Steel Bridge Superstructures	2.0
34. PROJECT: Support for AASHTO Committees and Councils. Roadmap for the Transformation to Computer Simulation-Based Assessment of Bridge Railings	1.8
85. PROJECT: Comprehensive Evaluation of Design Standards, Materials, and Construction for Slip Formed Concrete Bridge Railings to Alleviate Sources of Early Age Deterioration	1.8
122. PROJECT: Effects of Construction Installation Methods on the Design and Performance of Drilled Shaft Foundations	1.8
151. PROJECT: Design of 3D Printable Eco-Concrete by Utilizing Rheology Modifiers for Sustainable Infrastructure	1.8
156. PROJECT: Automated Curing and Strength Monitoring of Sensor-Embedded 3D Printed Transportation Infrastructure	1.8
165. PROJECT: TRC2204 - Materials and Testing for Drilled Shaft Concrete	1.8
167. PROJECT: TRC2202 - Updating ARDOT Liquefaction Evaluation Procedures	1.8
190. PROJECT: Field deployment and verification of an AI-based crowdsensing bridge condition assessment platform	1.8
205. PROJECT: Develop Enhanced Protection of Median Openings between Parallel Bridge Structures	1.8
243. PROJECT: Research for AASHTO Standing Committee on Highways. Task 396. Updating the AASHTO Seismic Hazard Maps and Site Coefficients	1.8
263. PROJECT: Behavior of the Expanded Polystyrene (EPS) Elastic Inclusion at Integral Abutments	1.8
292. PROJECT: Steel Bridge Coating Inventory 2021	1.8
333. PROJECT: Remote Electronic Water Level Sensors for Monitoring Scour Critical Structures	1.8
334. PROJECT: Developing ABC Success Index to Support Contractors During Pre-Project Planning	1.8
335. PROJECT: Improving Deep Learning Models for Bridge Management Using Physics-Based Deep Learning	1.8
344. PROJECT: Risk and Resilience of Bridges: Toward Development of Hazard-Based Assessment Framework, Research Needs, and Benefits of Accelerated Construction	1.8
356. PROJECT: Synthesis Study Quantifying the Effect of UHPC Fiber Dispersion and Orientation in Structural Members	1.8

Project Number (from the original list) and Name	Ave Rank
368. PROJECT: UAV Based Inspections for Highway Bridge and Structural Condition Monitoring and Inspection Works	1.8
379. PROJECT: Earthquake-Induced Damage Classification of Bridges Using Artificial Neural Networks	1.8
386. PROJECT: Adjustable Cross-frames for the Erection of Steel Girder Bridges	1.8
410. PROJECT: Uncertainties in liquefaction assessment and its economic impact	1.8
411. PROJECT: Residual cable strength fatigue testing	1.8
415. PROJECT: Improved UAV-Based Structural Inspection Techniques and Technologies for Northeast Bridges (1.12)	1.8
432. PROJECT: Use of Toughened Epoxies to Fill Gaps Between Plates for Steel Bridge Construction	1.8
440. PROJECT: Develop design aid charts and tables for selecting preliminary physical security protection measures for bridges.	1.8
453. PROJECT: Develop and Validate Precast Column Solutions for Texas Bridges	1.8
483. PROJECT: Rapid Repair of Cracks on the Embankment Slopes Using Bio-Cement	1.8
510. PROJECT: Midwest Guardrail System (MGS) Thrie Beam Approach Guardrail Transition (AGT) Retrofit to Existing Concrete Parapets and Bridges	1.8
518. PROJECT: Concrete Mix Designs for Partial-Depth Link Slabs and Deck Extension	1.8
524. PROJECT: Temperature Effects in Match Cast Segmental Bridge Construction	1.8
529. PROJECT: Development of a Multi-scale Self-healing High-volume Fly Ash UHPC	1.8
530. PROJECT: Test Methods and Bond Performance Characterization of Shotcrete-Concrete Interface	1.8
560. PROJECT: Developing the Load Distribution Formula for Louisiana Culverts	1.8
578. PROJECT: Development of Comprehensive Inspection Protocols for Deteriorated Steel Beam Ends	1.8
580. PROJECT: Bridge Project Prioritization (Phase 1)	1.8
582. PROJECT: Support for AASHTO Committees and Councils. Update Proposed Manual for the Maintenance of Roadways and Bridges	1.8
603. PROJECT: Use of UHPC in Conjunction with Pneumatic Spray Application and Robotic for Repair and Strengthening of Culverts- Phase I	1.8
606. PROJECT: Rapid Repair and Retrofit of Timber Piles Using UHPC	1.8
612. PROJECT: Development of a System-Level Distributed Sensing Technique for Long-Term Monitoring of Concrete and Composite Bridges (C11.2019)	1.8
622. PROJECT: Functional Composite-Based Wireless Sensing Platform for Bridge Structures	1.8
631. PROJECT: Complex Network Perspectives Towards Accelerated Bridge Construction (ABC)	1.8
644. PROJECT: Implementation of Culvert Design Guide for Stream Connectivity and Aquatic Organism Passage (AOP)	1.8
683. PROJECT: Develop Cost Effective Alternatives for Mitigating Debris and Environmental Impacts Around Bridge Piers	1.8
704. PROJECT: Proposed Modification to AASHTO LRFD Bridge Design Specifications, Section 13—Railing	1.8

Project Number (from the original list) and Name	Ave Rank
708. PROJECT: Lateral Loading of Unreinforced Rigid Elements and Basal Stability of Column-Supported Systems (3.12)	1.8
710. PROJECT: Eliminating Column Formwork Using Prefabricated UHPC Shells	1.8
733. PROJECT: Experimental Validation of a Rapid Assessment Tool for Pile Capacity and Stability in Response to Scour Situations	1.8
735. PROJECT: Finite element model updating for bridge deformation measurements extracted from remote sensing data	1.8
753. PROJECT: Evaluation of Concrete Pile to Footing or Cap Connections	1.8
757. PROJECT: Develop a Formula for Determining Scour Depth around Structures in Gravel-bed Rivers	1.8
797. PROJECT: Design of CFST Components and Connections for Transportation Structures: Course Module	1.8
819. PROJECT: SPR-4310: Legal and Permit Loads Evaluation for Indiana Bridges	1.8
838. PROJECT: Research for AASHTO Standing Committee on Highways. Task 415. Proposed AASHTO Guidelines for Bottom Flange Limits of Steel Box Girders	1.8
848. PROJECT: Comparing the Design and use of Different Types of Grade Control at Culverts TR-750	1.8
17. PROJECT: High Performance Computational Fluid Dynamics (CFD) Modeling Services for Highway Hydraulics	1.6
19. PROJECT: Implementation of Shallow Foundations on Florida Limestone in FB-MultiPier	1.6
76. PROJECT: Development of a Fatigue Load for Railway Bridges	1.6
89. PROJECT: Settlement Criteria and Design Approach for Embankments and Retaining Walls Built on Compressible Soils	1.6
107. PROJECT: RES2023-03: Automatic Tools for Quick and Accurate Construction Cost Estimation for Retaining Walls	1.6
131. PROJECT: Response of Bed Shear Stress in Open-Channel Flow to a Sudden Change in Bed Roughness	1.6
168. PROJECT: Physics-Informed Machine Learning of Fluid-Structure Interaction for Bridge Safety and Reliability	1.6
170. PROJECT: Strategic Prioritization in Bridge Asset Maintenance Through Data-Driven Long-Term Asset Valuation with Additional Emphasis on Promoting GDOT’s Partnerships with Counties	1.6
188. PROJECT: Best Practice for Steel Bridge Coating and Recoating Warranty Contract Requirements	1.6
192. PROJECT: Operational Baseline and Structural Health Monitoring for the 2nd Avenue Network Arch Bridge	1.6
201. PROJECT: Steel Suspension Bridge Vulnerability and Countermeasures	1.6
207. PROJECT: SPR-2323: Highway Sign Support Systems: Condition Assessment Deterioration Models and Asset Management	1.6
210. PROJECT: Optimal Selection of Upgrade and Maintenance Interventions to Minimize Life-Cycle-Cost	1.6
232. PROJECT: Structural Integrity, Safety, and Durability of Critical Members and Connections of Old Railroad Bridges under Dynamic Service Loads and Conditions (1.13)	1.6
293. PROJECT: Spot, Zone, and Overcoat Painting of Steel Bridges	1.6

Project Number (from the original list) and Name	Ave Rank
295. PROJECT: UAV-enabled Structure from Motion Photogrammetry for Bridge Crack Detection	1.6
339. PROJECT: An Interactive System for Training and Assisting Bridge Inspectors in the Inspection Video Data Analytics (WD-4)	1.6
355. PROJECT: Bridge Pile Repair Using Underwater Fiber-Reinforced Polymer (FRP) Sleeve and Steel Reinforced Grout	1.6
367. PROJECT: Integration of Aerial Manipulation, Haptics-based Human-in-the-Loop Control, and Augmented Reality for Bridge Deck Hosing (AS-9)	1.6
389. PROJECT: Effective wildlife fences through better functioning barriers at access roads and jump-outs	1.6
391. PROJECT: Wildlife Vehicle Collision Reduction and Habitat Connectivity	1.6
392. PROJECT: Steel Bridge Materials and Detailing Research	1.6
397. PROJECT: TRC2103 - Developing Guidelines for Evaluating Weathering Steel Bridges	1.6
409. PROJECT: In-Service Performance Evaluation of NETC Steel Bridge Railings	1.6
413. PROJECT: Advanced Sensing Technologies for Practical UAV-Based Condition Assessment (C20.2020)	1.6
417. PROJECT: Developing Scour-Depth Estimation Using the In Situ and Portable Scour Testing Devices (ISTD and PSTD) for Illinois Cohesive Soils	1.6
428. PROJECT: Educating Professionals for Practice in Highway Bridge Engineering	1.6
433. PROJECT: Tightening Criteria for Stainless Steel Bolts	1.6
442. PROJECT: Synthesis on the Scour Appraisal Process and Scour Plan of Action	1.6
454. PROJECT: Evaluate the Deployment of High Strength Reinforcing Steel in Texas	1.6
455. PROJECT: Synthesis: Rip-Rap for Scour Countermeasures	1.6
468. PROJECT: Evaluation of Traffic Crash Characteristics on Elevated Sections of Interstates in Louisiana	1.6
493. PROJECT: Mass Concrete Mixtures Optimized For Temperature Control and Workability	1.6
509. PROJECT: Rapid Concrete Bridge Repair Survey and Patch Material Evaluation	1.6
517. PROJECT: Feasibility of 3D Printing Applications for Highway Infrastructure Construction and Maintenance	1.6
520. PROJECT: Experimental Validation of New Improved Load Rating Procedures for Deteriorated Unstiffened Steel Beam Ends	1.6
542. PROJECT: Safe and Cost-Effective Reduction of Load Postings for South Carolina Bridges	1.6
554. PROJECT: Inspection of Flexible Filler Tendons	1.6
562. PROJECT: Energy Harvesting for Self-Powered Sensors for Smart Transportation Infrastructures	1.6
576. PROJECT: Loading and Wetting-Induced Settlement of Bridge Approach Embankment Materials	1.6
592. PROJECT: Performance of Corroded Piles Subjected to Eccentric Loads Before and After Repair	1.6
600. PROJECT: Multi-Span Lateral Slide Laboratory Investigation: Phase 1	1.6

Project Number (from the original list) and Name	Ave Rank
607. PROJECT: Automated MFL System for Corrosion Detection	1.6
611. PROJECT: Alternative Materials and Configurations for Prestressed-precast Concrete Pile Splice Connection	1.6
625. PROJECT: AASHTO Guide Specification for ABC Design and Construction--Implementation Workshops	1.6
657. PROJECT: Bridge and Culvert Hydraulics including Aquatic Organism Passage	1.6
672. PROJECT: Determination of Micropile Connection Flexural Resistance	1.6
687. PROJECT: Structural Behavior of Tall Haunches in TxDOT Beam and Girder Bridges	1.6
695. PROJECT: Performance Assessment of Jointless Abutments in Virginia	1.6
713. PROJECT: Leveraging High-Resolution LiDAR and Stream Geomorphic Assessment Datasets to Expand Regional Hydraulic Geometry Curves for Vermont: A Blueprint for New England States (C5.2018)	1.6
718. PROJECT: Guidelines for Corrosion Protection of Steel Bridges Using Duplex Coating Systems	1.6
721. PROJECT: RES2019-22: Geosynthetic Reinforced Soils for Bridge Approach Slab Support	1.6
729. PROJECT: Development of GFRP Reinforced Single Slope Bridge Rail	1.6
746. PROJECT: Efficient Service Life Extension of Bridges through Risk-based Life-cycle Management and High-performance Construction Materials: Emphasis on Corrosion-resistant Steel	1.6
759. PROJECT: Mixed Reality Assisted Infrastructure Inspections	1.6
762. PROJECT: BIRDS: Bridge Inspection Robot Deployment Systems (AS-4)	1.6
795. PROJECT: Structural Assessment of Maryland Sign Structures based on AASHTO LTS- 6 Strength and Fatigue Criteria	1.6
804. PROJECT: Developing Implementation Strategies for Risk Based Inspection (RBI)	1.6
817. PROJECT: Condition/Health Monitoring of Railroad Bridges for Structural Safety, Integrity, and Durability (1.2)	1.6
823. PROJECT: Feasibility Study of 3D Printing of Concrete for Transportation Infrastructures TR-756	1.6
833. PROJECT: Use of Life Cycle Cost Analysis to Enhance Inspection Planning for Transportation Infrastructure	1.6
851. PROJECT: Fill Material at Integral End Bents	1.6
856. PROJECT: New Seismic-Resisting Connections for Concrete-Filled Tube Components In High-Speed Rail Systems	1.6
858. PROJECT: Evaluation of Bridge Rail Systems to Confirm AASHTO MASH Compliance	1.6
698. PROJECT: Steel Reinforcement Section Loss Guidance Tables	1.5
22. PROJECT: Effectiveness of Short Solid Barriers to Reduce Noise Generated by Different Types of Highway Vehicles	1.4
33. PROJECT: GIS Tools to Identify Bridges with Bats	1.4

Project Number (from the original list) and Name	Ave Rank
53. PROJECT: Synthesis of Information Related to Highway Practices. Topic 54-09. Hydraulic Engineering Practices for Construction and Temporary Facilities in Streams and Rivers	1.4
56. PROJECT: Criteria of Welded Splices on Cold-Bent Reinforcing Steel	1.4
57. PROJECT: Bridge Avoidance in River-based Drone Autonomy	1.4
74. PROJECT: Synthesis of Information Related to Highway Practices. Topic 54-19. Practices for Controlling Tunnel Leaks	1.4
88. PROJECT: Synthesis: Develop Guidance for Local Government Building Codes for Bridges	1.4
100. PROJECT: SPR-4736: A Study of Suburban Arterial Safety Performance Based on Median Type	1.4
110. PROJECT: A Real-Time Ice Warning System Empowered by Dielectric Ice Sensors for Bridges	1.4
111. PROJECT: Hyperspectral Imaging and Analysis for Steel Paint Condition Assessment (SN-9)	1.4
152. PROJECT: Climate Change Impacts on Asset Management of Texas Concrete Bridges	1.4
153. PROJECT: Environmental Friendly Applications of Ground Tire Rubber (GTR) In Producing Concrete	1.4
160. PROJECT: Deep Reinforcement Learning-based Digital Twin for Risk Improved Decision Making in Transportation Construction	1.4
186. PROJECT: Skew Detection System Replacement on Vertical Lift Bridges (Phase II)	1.4
235. PROJECT: Using Deep Learning for Accurate Detection of Bridge Performance Anomalies	1.4
258. PROJECT: SPR-4622: Integration of BIM for Bridge Modeling	1.4
299. PROJECT: Application of Steel Sheet-Piles for the Abutment of Water-Crossing Bridges in Nebraska	1.4
351. PROJECT: Effective Bridge Deck Weather Warning Technologies	1.4
365. PROJECT: CCTRP 20-02: End Encasement for the Construction of Maintenance-Free Steel Bridges	1.4
366. PROJECT: CCTRP 20-03: Protection Against Corrosion of Steel in Concrete Using Epoxy/LDH Coatings	1.4
372. PROJECT: Impact of Construction Eccentricity on Direct Pier-to-Pile Connections for Permanently Cased Shaft (CFST) Piles	1.4
378. PROJECT: Condition Evaluation of Precast Post-tensioned Concrete Girder Bridges During Fires from Distributed Fiber Optic Sensors	1.4
418. PROJECT: Analysis of Mitigating Concrete Cracks with Bacteria	1.4
426. PROJECT: Post-tensioning Tendon Force Assessment for Bridges	1.4
427. PROJECT: Bridge Post-tensioning Training and Testing Center	1.4
431. PROJECT: Bridge Management Systems Workshop Delivery	1.4
444. PROJECT: Integration of Non-destructive Evaluation (NDE) into Bridge Management Systems	1.4
448. PROJECT: Assessment of Corrosion for Buried Metallic Foundations and Elements	1.4
469. PROJECT: Life Extension of Fatigue-Damaged Highway, Rail, and Transit Bridges: Identifying Actual Crack Tip	1.4

Project Number (from the original list) and Name	Ave Rank
496. PROJECT: A Feasibility Study of Road Culvert Bridge Deck Deicing Using Geothermal Energy	1.4
499. PROJECT: Protecting Critical Civil Infrastructure Against Impact from Commercial Vehicles – Phase II, A Systems Based Approach	1.4
500. PROJECT: Pullout Resistance of Reinforcement in Lightweight Cellular Concrete Fill	1.4
508. PROJECT: Energy Dissipation Optimization for Circular Culverts	1.4
540. PROJECT: Design Guidelines and Mitigation Strategies for Reducing Sedimentation of Multi-Barrel Culverts	1.4
556. PROJECT: Virginia Weathering Steel Assessment on I-66 Corridor	1.4
588. PROJECT: Robot-Assisted Underwater Acoustic Imaging for Bridge Scour Evaluation (AS-8)	1.4
591. PROJECT: Investigation and Development of a MASH Test Level 6, Cost-Effective Barrier System for Containing Heavy Tractor Tank-Trailer Vehicles and Mitigating Catastrophic Crash Events – Phase III	1.4
596. PROJECT: Data-Driven Risk-Informed Bridge Asset Management and Prioritization Across Transportation Networks (RR-2)	1.4
613. PROJECT: SPR-4445: Long Term Project and Network Level NDT Implementation Plan for Indiana	1.4
659. PROJECT: Load Transfer from Track to Bridge Structure on Curves	1.4
670. PROJECT: Initial Analytical Investigation of Cantilever and Butterfly Steel Overhead Sign Trusses with Respect to Remaining Fatigue Life	1.4
682. PROJECT: Traffic Disruption-Free Bridge Inspection Initiative with Robotic Systems	1.4
690. PROJECT: Improving Connectivity: Innovative Fiber-Reinforced Polymer Structures for Wildlife, Bicyclists, and/or Pedestrians	1.4
751. PROJECT: Evaluating Wildlife Use of the South Jackson Project Highway Crossing Structures	1.4
779. PROJECT: High Performance Concrete with Post-Tensioning Shrinking Fibers (2.7)	1.4
793. PROJECT: Using Unmanned Aerial Systems to Augment Monitoring Aufeis Directly Under Bridges	1.4
798. PROJECT: Unmanned Aircraft Systems Impact on Operational Efficiency and Connectivity	1.4
805. PROJECT: Guidance on Seismic Site Response Analysis with Pore Water Pressure Generation	1.4
809. PROJECT: Continuous Field Validation of a Wireless Structural Monitoring and Bridge Weigh-In-Motion (BWIM) System	1.4
830. PROJECT: Use of Cold Gas Dynamic Spraying for Repair of Steel Structures TR-758	1.4
855. PROJECT: Monitoring Transportation Structure Integrity Loss and Risk with Structure-From-Motion	1.4
24. PROJECT: Experimental Tests for an Effective Barrier Design to Exclude Diamondback Terrapins (Malaclemys terrapin) from Roads	1.2
58. PROJECT: Planning Project for Initiating A Large-scale 3D Printing Facility	1.2
61. PROJECT: Ecological Impacts of Sediment Derived from Bridge Construction	1.2
94. PROJECT: Synthesis of Lacustrine Wave Scour Evaluation Methods	1.2
127. PROJECT: Enhancing the Resilience of Coastal Box Girder Bridges through Geometric Modifications	1.2

Project Number (from the original list) and Name	Ave Rank
139. PROJECT: Use of 3D Seismic Waveform Tomography with SPT Source for Geotechnical Site Characterization	1.2
171. PROJECT: Holistic digital twins for transportation infrastructure	1.2
174. PROJECT: Digital Twin Technologies Towards Understanding the Interactions between Trans. and other Civil Infrastructure Systems: Phase 2	1.2
218. PROJECT: Non-Cantilever Fatigue Remaining Life Simulation Software Using Probabilistic Wind Model for All Counties in Kansas	1.2
259. PROJECT: Real-Time Flood Forecasting for River Crossing - Phase IV	1.2
318. PROJECT: Performance metrics for bridge approach profiles	1.2
323. PROJECT: Synthesis of Information Related to Highway Practices. Topic 53-13. Practices for Steel Bridge Fabrication and Erection Tolerances	1.2
328. PROJECT: Confinement Effect of Narrow Baseplates or Reaction Area on Anchor Breakout, Part 2	1.2
347. PROJECT: Construction of Three Large-Scale Robots Capable of Constructing UHPC Shell, Repair of Culvert and Automated MFL	1.2
348. PROJECT: Integrated Flood and Socio-Environmental Risk Analysis for Prioritizing ABC Activities	1.2
385. PROJECT: Fatigue Crack Inspection Using Computer Vision and Augmented Reality	1.2
393. PROJECT: Efficacy of 3D Printing for Steel Bridge Fabrication	1.2
400. PROJECT: Development of a New Airborne Portable Sensing System to Investigate Bridge Response	1.2
405. PROJECT: Proposed AASHTO Specifications for Design of Piles for Downdrag	1.2
414. PROJECT: Assessment and Evaluation of Post-Liquefaction Lateral Spread Impact on Bridge Deep Foundations	1.2
443. PROJECT: Scour peer exchanges on updates to HEC documents and development of NextScour	1.2
446. PROJECT: 2020 LTBP Data Collection	1.2
470. PROJECT: MSE Wall Survey of Corrosion Progress – Joint Project with KSU	1.2
522. PROJECT: Wildlife Barriers at Access Roads Along a Highway in a Multi-Functional Landscape on the Flathead Indian Reservation	1.2
525. PROJECT: Framework for Culvert Asset Management in Alaska	1.2
537. PROJECT: Synthesis of Information Related to Highway Practices. Topic 52-01. State of Practice on Infrastructure Inspections for the Digital Age	1.2
538. PROJECT: Synthesis of Information Related to Highway Practices. Topic 52-12. Rehabilitation of Culverts and Buried Storm Drain Pipes	1.2
546. PROJECT: Scour Analysis at Missouri Bridges	1.2
581. PROJECT: Development of Dual-Purpose Desert Tortoise Crossing Culverts (NDOT 733-19-803)	1.2
590. PROJECT: Probability of Detection in Corrosion Monitoring with FE-C Coated LPFG Sensors (SN-8)	1.2
599. PROJECT: Investigation of the Efficacy of Helical Pile Foundation Implementation in Accelerated Bridge Construction Projects – Phase I	1.2
605. PROJECT: Robotic Bridge Construction: Experimental Phase I	1.2

Project Number (from the original list) and Name	Ave Rank
615. PROJECT: Low Temperature Performance of a Friction Pendulum Bearing Inundated with Ice	1.2
648. PROJECT: Hydraulic Inspection Vehicle Explorer (HIVE) Culvert Upgrade	1.2
694. PROJECT: Inspection Training Course on Bridge Preventive Maintenance Activities	1.2
707. PROJECT: Fatigue Characterization and Improvement of Cantilevered Sign Structure Box Connections	1.2
723. PROJECT: Concrete Box Culvert Earth Pressure Monitoring	1.2
727. PROJECT: Lateral Slide of Multi-Span Bridges: Investigation of Connections and Other Details Phase I	1.2
743. PROJECT: Strategic Prioritization and Planning of MultiAsset Transportation Infrastructure Maintenance, Rehabilitation, and Improvements: Phase 1 – Prioritization through Optimization	1.2
744. PROJECT: Development of a Practical Risk Framework for Railway Bridge Stiffness Transition Maintenance and Upgrade	1.2
748. PROJECT: Epoxy Dowel Pile Splice Evaluation	1.2
752. PROJECT: Performance Evaluation of Very Early Strength Latex Modified Concrete TR-771 (Phase III of TR-690)	1.2
756. PROJECT: Mitigation of Differential Settlement at Highway Bridge Approaches	1.2
763. PROJECT: Autonomous Ultrasonic Thickness Measurement by a Magnet-Wheeled Robot (SN-6)	1.2
780. PROJECT: Distributed Fiber Optic Sensing System for Bridge Monitoring (1.5)	1.2
790. PROJECT: SPR-4309: Pack Rust - Mitigation Strategy Effectiveness	1.2
820. PROJECT: Cascadia Ground Motion Estimates in Comparison to ODOT Design Criteria	1.2
825. PROJECT: Development of MASH Computer Simulated Steel Bridge Rail and Transition Details	1.2
826. PROJECT: Development of an Integrated Unmanned Aerial Systems (UAS) Validation Center	1.2
827. PROJECT: Delivering Maintenance and Repair Actions via Automated/Robotic Systems	1.2
836. PROJECT: Guidelines for Risk-Based Inspection and Strength Evaluation of Suspension Bridge Main Cable Systems	1.2
840. PROJECT: Fracture Resistance of Cold Bent Steel	1.2
843. PROJECT: TRC1902 - Capillary Pressure Sensor Testing to Identify Curing Regimen in Freshly Placed Bridge Decks	1.2
847. PROJECT: Bridge-stream network assessment to identify sensitive structural, hydraulic and landscape parameters for planning flood mitigation (4.4)	1.2
3. PROJECT: Evaluation of Coating Materials Using Accelerated Laboratory Weathering Test Protocol	1.0
39. PROJECT: SPR-4734: Expediting and Enhancing the Hydraulic Site Data Collection Process	1.0
108. PROJECT: Management Plan for Historic Bridges in Virginia Update	1.0
128. PROJECT: SPR-2322: Artificial Intelligence (AI) and Markov Process Based Data Mining on Predicting Bridge Operating Conditions	1.0
141. PROJECT: Bat Use of Bridges and Culverts	1.0

Project Number (from the original list) and Name	Ave Rank
145. PROJECT: Stabilization of Expansive Soils using Geopolymers Prepared from Locally Available Resources	1.0
146. PROJECT: Monitoring of Transportation System Assets using Synthetic Aperture Radar (SAR) Satellite Data	1.0
148. PROJECT: Framework of Internal Damage Identification in Inhomogeneous Medium Interweaving Wave Scattering Model and Deep Learning	1.0
173. PROJECT: Methods to Identify Problematic Carriers and Prevent Infrastructure Damage	1.0
182. PROJECT: SMART Shear Keys for Tsunami/Storm Surge-Hazards Mitigation of Concrete Girder Bridges	1.0
223. PROJECT: Continued Advancements in Load and Resistance Factor Design (LRFD) for Foundations, Substructures and Other Geotechnical Features	1.0
224. PROJECT: Administration of Highway and Transportation Agencies. Collective and Individual Actions for State Departments of Transportation Envisioning and Realizing the Next Era of America's Transportation Infrastructure – Phase I	1.0
238. PROJECT: Synthesis of Information Related to Highway Practices. Topic 53-06. Local Calibration of LRFD Geotechnical Resistance Factors	1.0
240. PROJECT: Digital Twins to Increase Mobility in Rural South Carolina	1.0
244. PROJECT: Research for AASHTO Standing Committee on Highways. Task 403. Develop Detailed Elements for Movable Bridge Inspection and Management	1.0
256. PROJECT: Mixed Reality-Assisted Element Level Inspection and Documentation	1.0
281. PROJECT: Integration of Repair and Remediation Methods into Pipe Material Selection Approach	1.0
286. PROJECT: Automated Data and Feature Extraction from Bridge Plan	1.0
289. PROJECT: Enhancing the ABS ACOUSTIC BUBBLE SPECTROMETER® for Kansas	1.0
290. PROJECT: Predicting Critical Shear Stress of Cohesive Sediments/Soils in Riverbeds	1.0
305. PROJECT: Evaluate MDT Electrified Wildlife Deterrent Mats	1.0
306. PROJECT: Updates to Bridge Security Engineering and Design for AT Planner Bridges	1.0
310. PROJECT: Training Manual for SDDOT's LRFD Shallow Foundation Design Method	1.0
317. PROJECT: Use of Drilling Parameters for Enhancing Geotechnical Site Investigations	1.0
324. PROJECT: Proposed AASHTO Guideline for Load Rating of Segmental Bridges	1.0
352. PROJECT: Combined Structural Health and Traffic Monitoring using Fiber Optic Distributed Acoustic Sensing	1.0
357. PROJECT: Investigation and Development of a MASH Test Level 6, Cost-Effective Barrier System for Containing Heavy Tractor Tank-Trailer Vehicles and Mitigating Catastrophic Crash Events – Phase IV	1.0
375. PROJECT: Evaluating Hydraulic Spread Calculations and Closed Drainage Performance System	1.0
376. PROJECT: Evaluation of the Bonner Bridge Girders: Assessing Residual Capacity, Prestressing Losses and Degradation of the 56 Year Old Members	1.0
382. PROJECT: Understanding of Bridge Vulnerability to Climate Change Enables Pro-active Adaptation Measures	1.0

Project Number (from the original list) and Name	Ave Rank
383. PROJECT: SPR-4535: Development of a Formalized Program for In-service Inspection of Pedestrian Bridges	1.0
398. PROJECT: Seamless Comparative Modeling of Natural Hazards Using the Material Point Method	1.0
447. PROJECT: 2020 LTBP Data Analysis	1.0
456. PROJECT: Develop Refined Design Methods for Lean-On Bracing	1.0
457. PROJECT: Evaluate Improved Streamflow Measurement Technologies at TxDOT Bridges	1.0
480. PROJECT: Development of a Multi-Level Dynamic Model to Measure the Resilience Level of Transportation Infrastructure Networks: A Comprehensive Approach to Quantification of Resilience Dimensions in Highway and Bridge Projects	1.0
491. PROJECT: Guidance on Foundation Design Assumptions with Respect to Loose/Soft Soil Effects on Pile Lateral Capacity and Stability	1.0
516. PROJECT: Culvert Rehabilitation using 3D Printed Diffusers (2.11)	1.0
519. PROJECT: Impacts of Fish Passage Culvert Slipline	1.0
547. PROJECT: Development of New Generation of Portable Concrete Barriers	1.0
557. PROJECT: Characterization of Weld Flaw Size	1.0
571. PROJECT: Evaluating Nonlinear Methods for Flood Hydrograph Generation to Evaluate Bridge Scour	1.0
573. PROJECT: Descriptive and Predictive Deep Learning Analytical Tools for Enhanced Bridge Management	1.0
579. PROJECT: Analysis and Modernization of Bridge Construction Cost Database	1.0
624. PROJECT: Development of New Design Guidelines for Protection Against Erosion at Bridge Abutments - Phase III	1.0
627. PROJECT: Assessments of Cracks in Hollow Prestressed Concrete Bridge Cylinder Piles	1.0
628. PROJECT: RES2020-10: Guidelines for the Use of Expanded- Polystyrene (EPS) Block Geofoam as Lightweight Backfill Behind Retaining Walls	1.0
632. PROJECT: Understanding Critical Impacting Factors and Trends on Bridge Design, Construction, and Maintenance for Future Planning	1.0
637. PROJECT: Multi-Criteria decision-making approach for Building Resilient and Sustainable Transportation Infrastructure	1.0
638. PROJECT: BridgeR—a Regional Seismic Hazard Assessment Tool for Transportation Networks & its Application to Freight Loss Assessment	1.0
639. PROJECT: Develop Bridge Weigh-in-Motion Approach to Measure Live Loads on Texas Highways	1.0
652. PROJECT: SPR-4419: Superabsorbent Polymers (SAP) for Internally Cured Concrete	1.0
661. PROJECT: Simulation of Degradation and Failure of Suspension Bridge Main Cables due to Natural and Anthropogenic Hazards	1.0
662. PROJECT: Determining Downstream Ecological Impacts of Sediment Derived from Bridge Construction	1.0
679. PROJECT: Evaluation of 2D Hydraulics Models to Improve Scour Predictions and Countermeasures	1.0
688. PROJECT: Development of Non-Fracture Critical Steel Box Straddle Caps	1.0
697. PROJECT: Phased Construction Bridges: Monitoring and Analysis for Traffic-Induced Vibration	1.0

Project Number (from the original list) and Name	Ave Rank
701. PROJECT: Proposed AASHTO Specifications for Design of Piles for Downdrag	1.0
711. PROJECT: Transportation Communication Tower Inspection Using Novel UAV Technologies	1.0
722. PROJECT: RES2019-08: Rating and Inventory of TDOT Retaining Walls	1.0
724. PROJECT: Improved Calculation of Scour Potential in Cohesive Soils and Scour Susceptible Rock	1.0
728. PROJECT: Measurement of Turbulent Flow Characteristics and Bed Shear Stress in Laboratory Soil Erosion Tests	1.0
749. PROJECT: Field Load Test and Geotech. Investigation Program for Development of LRFD Recomm. of Driven Piles on Intermediate GeoMaterials	1.0
771. PROJECT: Synthesis of Available Contracting Methods	1.0
778. PROJECT: Bridge Modal Identification via Video Processing and Quantification of Uncertainties (3.8)	1.0
807. PROJECT: Evaluation of Galvanized and Painted - Galvanized Steel Piling - TR-766	1.0
811. PROJECT: Investigation and Development of a MASH Test Level 6, Cost-Effective, Barrier System for Containing Heavy Tractor Tank-Trailer Vehicles and Mitigating Catastrophic Crash Event – Phase II	1.0
834. PROJECT: Evaluation of Lateral Pile Resistance Near MSE Walls at a Dedicated Wall Site - Phase 2	1.0
837. PROJECT: Fatigue Crack Control in Waterway Lock Gate Pintle Locations Subjected to Multi-Modal Fracture	1.0
849. PROJECT: Evaluation of Concrete Models in LS-DYNA to Develop a MASH Test Level 6 (TL-6) Barrier System – Phase I	1.0
850. PROJECT: Transportation Asset Management in Alaska	1.0
857. PROJECT: Crushed Hydraulic Cement Concrete Adjacent to Underdrains	1.0
18. PROJECT: Monitoring of Illegal Removal of Road Barricades using Intelligent Transportation Systems in Connected and Non-Connected Environments	0.8
45. PROJECT: Underwater Drone (ROV) Asset Review and Documentation	0.8
62. PROJECT: Determination of In-situ Rock Density and Strength with SH-Love Wave Tomography	0.8
157. PROJECT: Calcined Clays as Alternative Supplementary Cementitious Material and Precursor for Geopolymer Binders in Transportation Infrastructure	0.8
169. PROJECT: Utilization of Transportation Structures by Bats in Wyoming: A comprehensive investigation	0.8
183. PROJECT: A Dynamic Hurricane Risk Modeling Framework to Improve Bridge Safety under Changing Climate	0.8
187. PROJECT: Steel Bridge Coating and Recoating Warranty Requirements	0.8
202. PROJECT: Synthesis of Information Related to Highway Practices. Practices for Adding Bicycle and Pedestrians Access on Existing Vehicle Bridges	0.8
209. PROJECT: Handbook on Deterring and Excluding Bats from Transportation Structures	0.8
225. PROJECT: Synthesis of Information Related to Highway Practices. Topic 53-11. Resilient Design with Distributed Rainfall-Runoff Modeling	0.8
242. PROJECT: Wind Turbulence-Structure Interaction and Aeroelastic Instability for Long-Span Flexible Girder Systems	0.8
253. PROJECT: Sediment Control Approved Products List	0.8

Project Number (from the original list) and Name	Ave Rank
254. PROJECT: Development of Rapid Setting Soil-Cement Mixture Designs and Performance Testing	0.8
274. PROJECT: State-of-the-Art Technologies for Structural Health Monitoring of Tunnels: an Overview	0.8
277. PROJECT: Harkers Island Bridge Replacement: Material Characterization and Structural Performance	0.8
287. PROJECT: Impact Performance Assessment of Barrier Performance at High Speeds	0.8
291. PROJECT: Stochastic Models for Incorporating Traffic Reliability Goals in Roadway Improvement Scheduling	0.8
319. PROJECT: Fatigue Resistance of Fluted Lighting Poles	0.8
320. PROJECT: Rural Access Infrastructure Funding Process	0.8
361. PROJECT: Industrial Internet-of-Things Drilling & Incidentals	0.8
399. PROJECT: Crash Modeling of High-Profile Moving Vehicles under Strong Crosswinds Based on Computational Fluid Dynamics	0.8
406. PROJECT: Use of Geothermal Energy for De-icing Approach Pavement Slabs and Bridge Decks, Phase II	0.8
422. PROJECT: Resilience of Rural Communities and Transportation Networks to Hazards	0.8
423. PROJECT: Synthesis of Information Related to Highway Practices. Topic 52-02. Bridge Element Data and Use	0.8
424. PROJECT: Development of On-Bridge Stormwater Treatment Practices	0.8
425. PROJECT: Effective On-Bridge Treatment of Stormwater	0.8
449. PROJECT: Durability of Modified Helical Piles Under Lateral and Torsional Loads	0.8
475. PROJECT: Study on hybrid model combining super learner and physic-based models for SHM in bridges using low-cost BWIM	0.8
485. PROJECT: Calculating Pile Downdrag: Experimental and Numerical Investigations	0.8
550. PROJECT: Effects of Downdrag on Pile Performance	0.8
570. PROJECT: Investigating the Applicability of Multi-Fidelity Modeling to Condition Evaluation of Transportation Infrastructure	0.8
593. PROJECT: Investigation of Wind Effects on Bridges Induced by Tornadoes for Tornado-Resistant Design – Phase II	0.8
594. PROJECT: Nondestructive Data Driven Motion Planning for Inspection Robots (AS-5)	0.8
634. PROJECT: Phase II: Field Load Testing of Shallow Foundations in Florida Limestone	0.8
635. PROJECT: Assessing Axial Capacities of Auger Cast Piles from Measuring While Drilling	0.8
642. PROJECT: Annulus Void Fill Material for Rehabilitated Sliplined Culverts	0.8
643. PROJECT: Seasonal Use of ODOT Bridges by Bats	0.8
651. PROJECT: LRFD Procedure for Piles with Pilot Hole in Rock	0.8
665. PROJECT: Research for AASHTO Standing Committee on Highways	0.8

Project Number (from the original list) and Name	Ave Rank
669. PROJECT: SPR-4329: Verification Testing of MSE Wall Foundation Bearing Capacity Based on the DCPT	0.8
671. PROJECT: Develop Cloud-based Enhanced NBIAS and Provide Analyses for 25th & 26th C&P Reports	0.8
675. PROJECT: Identifying Bridges Critical to North Carolina Agriculture and Commerce	0.8
691. PROJECT: Evaluation of Vibration Mitigation Techniques for KDOT Cantilever and Butterfly Sign Structures	0.8
692. PROJECT: Work Plan for the Bridge Center and Bridge Engineer Program FY2020	0.8
699. PROJECT: Develop Enhanced Protection of Median Openings Between Parallel Bridge Structures	0.8
736. PROJECT: Condition-based Insp. and Restoration Scheduling of Pavement and Bridge Systems for Improved Post-disaster Infrastructure Systems Recovery	0.8
738. PROJECT: Laminated Wood Deck System for Folded Plate Girder	0.8
739. PROJECT: Robotics and Automation in ABC Projects: Exploratory Phase	0.8
750. PROJECT: Galena Creek Bridge Health Monitoring Instrumentation (NDOT 743-18-803)	0.8
792. PROJECT: Evaluation of Light Pole Foundation Embedment	0.8
814. PROJECT: Future-Proof Transportation Infrastructure through Proactive, Intelligent, and Public-involved Planning and Management (4.2)	0.8
853. PROJECT: Implementation of Recommendations for Eliminating Longitudinal Median Joints in wide Bridges	0.8
4. PROJECT: Assessing the Need for Floodplain Culverts Based on Geomorphology	0.6
5. PROJECT: Performance Testing of GRS Test Piers Constructed with Florida Aggregates - Axial Load Deformation Relationships	0.6
140. PROJECT: Using the PENCEL PMT to Evaluate Shallow Foundations at Florida's Fine Sand Sites	0.6
159. PROJECT: Investigating the Efficacy of Natural and Nature-based Features to Increase the Service Life of Coastal Roadways	0.6
162. PROJECT: Relaxation of Driven Piles in Florida Soils	0.6
163. PROJECT: Estimating the As-Placed Grout Volume of Auger Cast Piles	0.6
172. PROJECT: Phase II TCRP Project D-17 - Detecting and Mitigating Low Level DC Fault Currents in Transit Systems thus Eliminating Electrical Fires in Tunnels and Rights-of-Way	0.6
203. PROJECT: Incorporation of Social Equity Considerations into Transportation Asset Management	0.6
212. PROJECT: Administration of Highway and Transportation Agencies. Assessing and Communicating the Economic and Quality of Life Benefits of Transportation Infrastructure Investments: Message Testing	0.6
220. PROJECT: Critical Findings for Tunnel Functional Systems	0.6
246. PROJECT: Building Smarter Cities via Intelligent Asset Management: South Carolina Case Study using IBM Maximo Application	0.6
288. PROJECT: Interactive Decision Support System for Planning and Construction of Large-scale Tunneling Projects	0.6

Project Number (from the original list) and Name	Ave Rank
402. PROJECT: Advancing Subsurface Explorations Beyond the Borehole	0.6
404. PROJECT: Assessing Efficacy of Amphibian and Reptile Exclusion Fence (AREF) to Prevent Herpetofauna, with Emphasis on Houston Toad, from Entering Construction Zones	0.6
420. PROJECT: Texas Local Technical Assistance Program (LTAP)	0.6
466. PROJECT: Proposed AASHTO Guidelines for Implementation of MASH for Sign Supports, Breakaway Poles, and Work Zone Traffic Control Devices	0.6
479. PROJECT: Evaluation of Sustainable and Environmentally Friendly Stabilization of Cohesionless Sandy Soil for Transportation Infrastructure	0.6
504. PROJECT: Incorporating Snow Processes in the Iowa Flood Information System (IFIS) and Evaluating its Applicability for Nebraska	0.6
514. PROJECT: Update of Commercial Vessel Past Point Data for Designing Bridges Across Navigable Florida Waterways	0.6
515. PROJECT: Optimized materials for protection	0.6
526. PROJECT: Evaluation of Downdrag Loads on Bridge Pile Foundations in Inundated Collapsible Soils	0.6
536. PROJECT: Improving Design and Construction of Transportation Infrastructure through Bedrock Characterization	0.6
545. PROJECT: SC Flood Inundation Mapping	0.6
572. PROJECT: Modeling Disrupted Transportation Infrastructure System due to Multiple Hazards	0.6
597. PROJECT: “Smart Sounding System” for Autonomous Evaluation and Metallic Structures (IM-3)	0.6
641. PROJECT: The Effect of Rubber Fills on the Performance of Infrastructure, Phase 1	0.6
653. PROJECT: Railroad Tunnel Inspections for Maintenance and Replacement Prioritization Using Untethered Ground Penetrating Radar and LIDAR Capable Unmanned Aerial Vehicles (UAVs)	0.6
677. PROJECT: Research for AASHTO Standing Committee on Highways. Task 425. Emerging LED Technologies and Use within Tunnels	0.6
680. PROJECT: Evaluation of Hydrogel–stabilized Expansive Soils in Mississippi for Sustainable Maritime Infrastructure Design	0.6
730. PROJECT: Visualization and demonstration of risk identification and evaluation for extreme events	0.6
806. PROJECT: Wind Drag Coefficients for Highway Signs and Support Structures	0.6
835. PROJECT: Administration of Highway and Transportation Agencies. Performance Management Reporting Peer Exchange	0.6
52. PROJECT: Daytime Lighting in Short Tunnels	0.4
77. PROJECT: SEAHIVE – Sustainable Estuarine and Marine Revetment	0.4
371. PROJECT: Industrial Internet-of-Things Asset Monitoring, Phase 2	0.4
429. PROJECT: TBM Tunnel Liner Design Guidelines	0.4
430. PROJECT: Integrated FFFS-EVS Design Guidelines for Highway Tunnels	0.4
450. PROJECT: Investigating the Effectiveness of Enzymatic Stabilizers for Reclaimed Stabilized Base Projects (3.13)	0.4

Project Number (from the original list) and Name	Ave Rank
472. PROJECT: Compaction Multimeter	0.4
489. PROJECT: Internal Friction Angle of Sands with High Fines Content	0.4
492. PROJECT: Field Testing and Long-Term Monitoring of Selected High-Mast Lighting Towers	0.4
495. PROJECT: Leveraging Abandoned Railroad Tunnels for Bat Conservation	0.4
497. PROJECT: Real-Time Network Assessment and Updating Using Vehicle-Locating Data	0.4
552. PROJECT: Promoting the Adoption of Snow Fences through Landowner Engagement	0.4
633. PROJECT: Tsunami Design Forces for ABC Retrofit	0.4
658. PROJECT: Computational Fluid Dynamics Investigation of High Mast Illumination Poles: Influence of Light Fixtures	0.4
666. PROJECT: Cone Penetration Testing (CPT) for Illinois Subsurface Characterization and Geotechnical Design	0.4
678. PROJECT: Durability of Pipe Materials in Soils	0.4
717. PROJECT: Re-tightening the Large Anchor Rods of Support Structures for Signs and Luminaires: Phase II	0.4
783. PROJECT: Investigation of Wind Effects on Bridges Induced by Tornadoes for Tornado-Resistance Design – Phase I	0.4
815. PROJECT: Connected Vehicle Applications in Maine (4.1)	0.4
839. PROJECT: Light Pole Foundation Evaluation	0.4
1. PROJECT: Determination of Actual Derailment Loads on Transit Bridges	0.2
260. PROJECT: Evaluation of Corrugated HDPE Pipes Manufactured with Recycled Content	0.2
359. PROJECT: Salt Shed Design Template	0.2
384. PROJECT: Zero Speed Profiler Assessment for Pavement Smoothness and Continuous Pavement Texture Measurements	0.2
476. PROJECT: Feasibility Assessment of Warm Mix Asphalt in Arkansas	0.2
477. PROJECT: Effectiveness of Softening Agents for Enhancing Properties of Asphalt Mixes with High RAP Contents	0.2
498. PROJECT: Evaluation of Vibration Techniques for KDOT High Mast Illumination Poles	0.2
534. PROJECT: Development of Environmental Responsive Asphalt Technology for Asphalt Pavement Life Extension	0.2

Round 2 Rankings (208 Projects)

Project Number (from the original list) and Name	Y/N
7. PROJECT: Development of a Research Roadmap for ITD Bridge Section	Y
177. PROJECT: Mitigation Strategies for Cracking in Concrete Bridge Decks	Y
36. PROJECT: Use of Fiber-Reinforced Polymer Composites for Bridge Repairs in Montana	Y
67. PROJECT: Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology	Y
44. PROJECT: Evaluate Bridge Deck Condition and Replacement Methods	Y
221. PROJECT: Ultra-High Performance Concrete Connections Between Precast Bridge Deck Elements	Y
630. PROJECT: Cost-effective Bridge Decks for Improved Durability and Extended Service Life	Y
761. PROJECT: Precast Pier System for Accelerated Bridge Construction in Idaho	Y
32. PROJECT: High Bond Steel Fibers for Ultra High Performance Concrete (UHPC)	Y
37. PROJECT: Significant Factors of Bridge Deterioration	Y
46. PROJECT: Reduce Concrete Cracking through Mix Design	Y
54. PROJECT: Reducing the Cost and Facilitating Broader Adoption of Ultra-High-Performance Concrete (UHPC) in Bridges	Y
73. PROJECT: Durability and Volumetric Stability of Non-Proprietary Ultra High Performance Concrete Mixes Batched With Locally Sourced Materials	Y
80. PROJECT: Mitigating Cracks in Concrete Members for Durable Bridge Construction	Y
144. PROJECT: Stainless Steel Coated Rebar for Chloride Resistant Concrete Highways and Bridges	Y
147. PROJECT: Designing and Characterizing New Coating Materials to Increase the Corrosion Resistance of Steel Reinforcement Embedded in Concrete	Y
387. PROJECT: Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts (OHTI)	Y
559. PROJECT: Long-term Performance of HES Class 50AF Concrete with Polypropylene Fibers as Field-Cast Connection between Deck Bulb-T Girders in SH-36 Bridge over Bear River	Y
8. PROJECT: Implementation of Bridge Preservation Actions	Y
25. PROJECT: Computer Vision Tools for Bridge Inspections and Reporting	Y
47. PROJECT: SPR-4718: Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete	Y
68. PROJECT: Performance Evaluation of Reinforced Concrete Box Culverts	Y
114. PROJECT: Repair and Strengthening of Bridge Girders Using Ultra-High-Performance Concrete (UHPC)	Y
434. PROJECT: Rehabilitation of Deteriorated Bridge Decks with Ultra-High Performance Concrete Overlays	Y
501. PROJECT: Fatigue Life Analysis of Reinforced Concrete Beams Strengthened with Composites	Y

Project Number (from the original list) and Name	Y/N
532. PROJECT: Performance of ABC Columns and Cost-Effective Retrofit Strategies Subjected to Synergistic Distress Resulting From Corrosion and Seismic Loading	Y
51. PROJECT: Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands	Y
86. PROJECT: The Influence of Vehicular Live Loads on Bridge Performance	Y
101. PROJECT: Legal Truck Load Ratings for Standard Reinforced Concrete Boxes and Rigid Frame Boxes for HL-93 Loading	Y
143. PROJECT: Experimental Validation of Repair Methods for Earthquake-Damaged Bridges Incorporating ITD's Precast Pier System	Y
227. PROJECT: 2292 Innovative Multi-Hazard Resistant Bridge Columns for Accelerated Bridge Construction	Y
282. PROJECT: Exploration of UHPC Applications for Montana Bridges	Y
330. PROJECT: Performance of Cost-Effective Non-Proprietary UHPC in Thin Bonded Bridge Overlay	Y
381. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	Y
494. PROJECT: Fiber Reinforced Concrete Overlays for Bridge Structures	Y
506. PROJECT: Alternative High Early Strength Concrete (HESC) Structural Overlays	Y
535. PROJECT: Guide to Remediate Bridge Deck Cracking	Y
569. PROJECT: Reliability of ABC Grouted Coupler Connected Bridge Piers Subject to Vehicular Impact	Y
583. PROJECT: Evaluation of Thin Polymer Overlays for Bridge Decks	Y
715. PROJECT: UHPC Thin Bonded Overlay on Deteriorated Bridge Decks	Y
816. PROJECT: Development and Testing of High / Ultra-High Early Strength Concrete for durable Bridge Components and Connections (2.5)	Y
129. PROJECT: Steel-Free Concrete Bridge Decks (3.18)	N
132. PROJECT: Develop Countermeasure Strategies for Protecting Bridge Girders Against Overheight Vehicles Impact	Y
198. PROJECT: Rapid Post-Earthquake Displacement-Based Assessment Methodology for Bridges Phase I	N
241. PROJECT: Identification of Maintenance Practices to Impede Corrosion Impacts on Prestressed Concrete Box Beam Bridges	Y
297. PROJECT: SPR-4532: Synthesis Study: Repair and Durability of Fire Damaged Prestressed Concrete Bridge Girders	Y
676. PROJECT: Evaluating Integral Abutment Performance	Y
726. PROJECT: Performance Evaluation of Polyester Polymer Concrete Overlays Continuation Proposal Phase II TR-772	Y
784. PROJECT: Performance of Earthquake-Damaged Reinforced Concrete Bridges with Repaired Columns	N
788. PROJECT: Fiber-Reinforced Concrete in Bridge Decks TR-767	Y
9. PROJECT: Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails	Y
12. PROJECT: Earthquake-Induced Bridge Displacements	N

Project Number (from the original list) and Name	Y/N
20. PROJECT: Effective Timelines and Contractual Strategies for Accelerated Bridge Construction Projects	N
35. PROJECT: SPR-4731: Feasibility of 3D Scanning Technology for Bridge Inspection and Management	N
42. PROJECT: Shake Table Tests of Unique High-Strength Reinforced Piers	N
66. PROJECT: Laboratory Characterization of Fiber-Reinforced Polymer Reinforcement Material Properties and Surface Treatment Behavior in Concrete	Y
87. PROJECT: Utilization of 300 ksi Strands for TxDOT Prestressed Girders	N
93. PROJECT: Evaluate Performance of Sealers and Coatings Applied to TxDOT Bridge Substructures	N
95. PROJECT: Develop/Refine Design Provisions for Headed and Hooked Reinforcement	N
97. PROJECT: Vision-Based Detection of Bridge Damage Captured by Unmanned Aerial Vehicles (1.18)	N
99. PROJECT: Evaluation of Multi-Layer Polymer Concrete Overlays	Y
103. PROJECT: Evaluation of Structural Adhesives as "Steel Grouting" in Steel Bridge Repairs	N
104. PROJECT: Design of Stud Shear Connectors in Composite Steel Bridges	N
135. PROJECT: Development of Improved Inspection Techniques using LiDAR for Deteriorated Steel Beam Ends	N
138. PROJECT: Post-Fire Damage Inspection of Concrete Structures - Phase III - In-Situ Experimental Phase	Y
199. PROJECT: Impact of Response Spectra Definitions and Direct Displacement-Based Design Simplification for Multi-Span Bridges	N
200. PROJECT: Bridge Deck Preservation Portal	N
219. PROJECT: Field Trials for Cost-Effective Strengthening of SC Load Posted Bridges	N
283. PROJECT: Design and Development of High-Performance Composites for Improved Durability of Bridges in Rhode Island (2.17)	N
309. PROJECT: Mitigating Cracking in Ultra-High Performance Concrete (UHPC) Bridge Connections	N
369. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	Y
531. PROJECT: Fiber Reinforced Polymer (FRP) Seismic Retrofit of Reinforced Concrete Bridge Columns Vulnerable to Long-duration Subduction Zone Earthquakes	N
567. PROJECT: Effectiveness of Concrete Bridge Deck Sealants	Y
575. PROJECT: Durable Bridges Using Glass Fiber Reinforced Polymer and Hybrid Reinforced Concrete Columns	N
585. PROJECT: Durability Assessment of Externally Bonded FiberReinforced Polymer (FRP) Composite Repairs in Bridge	Y
620. PROJECT: Performance of Earthquake-Damaged Reinforced Concrete Bridges with Repaired Columns – Phase II	N
686. PROJECT: Development of Bridge Load Testing Program for Load Rating of Concrete Bridges	N
702. PROJECT: Strengthening of Pre-Tensioned Concrete Beams	N
716. PROJECT: Utilizing Steel Fibers as Concrete Reinforcement in Bridge Decks	N

Project Number (from the original list) and Name	Y/N
758. PROJECT: Assessment of Asbestos Containing Materials in Idaho Bridges	Y
760. PROJECT: Development of General Guidelines on The Effects of Bridge Span Range and Skew Angle Range on Integral Abutment Bridges (IABs) (3.7)	R
773. PROJECT: Development of Non-Proprietary UHPC Mix – Evaluation of the Shear Strength of UHPC (University of Washington)	Y
801. PROJECT: Repair Methods for Corrosion-Damaged Prestressed Concrete Girders	N
818. PROJECT: Textured Epoxy Coated and Galvanized Reinforcement to Reduce Cracking in Concrete Bridge Decks and Components	N
16. PROJECT: Achieving Resilient Multi-Span Bridges by using Buckling-Restrained Braces	N
43. PROJECT: Impact Test of GFRP Reinforced Bridge Barriers	N
48. PROJECT: Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies	Y
55. PROJECT: Design of Continuity Diaphragms Following New AASHTO Provisions	N
64. PROJECT: Structural Monitoring of Steel-Member Bridges with Fatigue Life Prognosis due to Dynamic Vehicular Loads	N
65. PROJECT: Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements	Y
78. PROJECT: Capacity Prediction of Repaired and Unrepaired Bridge Beams with Deteriorated Ends	Y
130. PROJECT: CT Girder Web Capacity and Design for Shear (3.17)	N
179. PROJECT: Bond Performance Between Precast UHPC Substrates and Field Cast UHPC Connections	N
189. PROJECT: Aerial Infrared Scanning of Bridge Decks for Detecting and Mapping Delamination	N
194. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase V	N
229. PROJECT: 2290 Bond Behavior of Epoxy Coated Reinforcement Bars in Non-Proprietary UHPC	N
251. PROJECT: Investigate Live Load Distribution and Stability of Prestressed Concrete Girders During Construction	N
278. PROJECT: Developing Deterioration Curves for Bridge Elements	R
302. PROJECT: Low-Cement Concrete Mixture for Bridge Decks and Rails	R
325. PROJECT: Post-Fire Damage Inspection of Concrete Structures Phase II – Experimental Phase	N
337. PROJECT: Data-Driven Decision-Making Framework for Inspection of Bridge Decks	Y
362. PROJECT: Testing and evaluation of energy absorbing panels for overheight collision impact protection	R
388. PROJECT: Feasibility of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Use in Highway Bridges in Montana: Implementation	R
394. PROJECT: Improvement of Approach Smoothness on Integral Abutment Bridges	N
463. PROJECT: Residual Capacity of Precast Prestressed Concrete (PPC) Deck Beams with Transverse Cracks	N
528. PROJECT: Impacts of Magnesium Chloride Deicer on the Durability of Nanosilica-Modified HVFA Concrete	N
555. PROJECT: Development of Deterioration Curves for Bridge Elements in Montana	Y

Project Number (from the original list) and Name	Y/N
601. PROJECT: Application of Methacrylate Polymers for Seismic ABC Connections	N
649. PROJECT: Bridge Column Footing Performance and Seismic Retrofit Evaluation Considering Soil-structure Interaction	N
650. PROJECT: Synthesis of Information Related to Highway Practices. Topic 51-13. Load Rating of Bridges and Culverts with Missing or Incomplete As-Built Information	N
668. PROJECT: Field Implementation and Monitoring of an Ultra-High Performance Concrete Bridge Deck Overlay	Y
693. PROJECT: Bridge Load Posting Based on Load Testing	N
696. PROJECT: Simple for Dead Continuous for Live (SDCL) Steel Girder Bridges with UHPC and GFRP	N
714. PROJECT: Cost-Effective Strategies for Retrofitting Culverts with Glass Fiber Reinforced Polymer	N
732. PROJECT: Development of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Iowa Bridges TR-773	N
767. PROJECT: Development of Non-Proprietary UHPC Mix (University of Oklahoma)	N
769. PROJECT: Development of Non-Proprietary UHPC Mix – Application to Deck Panel Joints (University of Nevada, Reno)	N
829. PROJECT: Sustainability and Resiliency of Concrete Rapid Repairs Utilizing Advanced Cementitious Materials – Freeze/Thaw Loads	N
6. PROJECT: Super-Elastic Copper-Based and Iron-Based Shape Memory Alloys and Engineered Cementitious Composites for Extreme Events Resiliency	N
26. PROJECT: NJDOT Corrosion Study on Steel Structural Members	N
27. PROJECT: Guide for 3D Model Viewers for Construction Inspection	N
31. PROJECT: Development of Deterioration Curves for Ohio Bridges	R
59. PROJECT: SPR-4730: Widening Reinforced Concrete Elements using Chemical Anchoring Systems (Post-installed Rebar Systems)	N
75. PROJECT: Synthesis of Information Related to Highway Practices. Topic 54-11. Quality Control Checks for Bridge and Structure Analysis Models	N
109. PROJECT: Entire Interior Culvert Lining with Engineered Cementitious Composites	N
115. PROJECT: QA/QC Guidelines on Drone-based Remote Sensing for Bridge Element Inspection (IM-4)	N
124. PROJECT: Modeling of Stainless-steel Reinforcement Corrosion	N
155. PROJECT: Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials	Y
166. PROJECT: TRC2203 - Low-Shrinkage Concrete Mixtures for Arkansas	N
176. PROJECT: CT Girder with FRP Shear Studs – Strength & Fatigue Testing	N
180. PROJECT: Connecting the DOTs: Implementing ShakeCast Across Multiple State Departments of Transportation for Rapid Post-Earthquake Response	N
181. PROJECT: Development of Non-proprietary Prefabricated Solutions for Concrete Barrier Systems for Accelerated Bridge Construction	N
196. PROJECT: Fiber Reinforced Concrete (FRC) Beam End Repairs for Corroded Steel Beam Ends	Y
206. PROJECT: Synthesis of Galvanized Steel Reinforcement Corrosion Performance	N

Project Number (from the original list) and Name	Y/N
213. PROJECT: CT Bridge Girder Sections with Precast Decks and FRP Girder-Deck Shear Connectors (3.16)	N
215. PROJECT: Protecting Critical Civil Infrastructure Against Impact from Commercial Vehicles – Phase 3, A Systems Based Approach Including Fire	N
249. PROJECT: Re-Examine Minimum Reinforcement Requirements for Shear Design	N
267. PROJECT: Increasing Bridge Durability and Service Life with LIDAR Enhanced Unmanned Aerial Systems (UAS)	N
285. PROJECT: Implementation of UHPC Technology into the New England Construction Industry (2.14)	N
301. PROJECT: Production of Cast-in-Place UHPC for Bridge Applications	N
322. PROJECT: Sustainable nHPC Mixtures for Durable Overlay of Concrete Bridge Decks in Cold Regions: Proof of Concept	N
326. PROJECT: Revised Load Rating Procedures for Deteriorated Prestressed Concrete Beams	N
354. PROJECT: Life-Cycle Cost Analysis of Ultra High-Performance Concrete (UHPC) in Retrofitting Techniques For ABC Project	N
403. PROJECT: Analysis of ABC Bridge Column-to-Footing Joints with Recessed Splice Sleeve Connectors	N
474. PROJECT: Field retrofit and testing of a corroded corrugated metal culvert using Glass Fiber Reinforced Polymers	N
507. PROJECT: Use of Sand Lightweight Concrete and All Lightweight Concrete to Improve Properties	N
533. PROJECT: Post-Earthquake Serviceability of RC Bridge Bents Using Visual Inspection	N
539. PROJECT: Quantitative Assessment of Soil-Structure Interaction (SSI) Effects on Seismic Performance of Bridges with ABC Connections	N
558. PROJECT: Concrete Systems for a 100-Year Design Life (2.2)	N
563. PROJECT: Assessment, Repair and Replacement of Bridges Subjected to Fire	Y
616. PROJECT: External Pocket and Socket Connections for the Seismic Design of Alaska Bridges	N
646. PROJECT: 2287 Evaluation of the Expected Life and Recoating of Silane Water Repellant Treatments on Bridge Decks	Y
740. PROJECT: Optimized performance of UHPC bridge joints and overlays	N
745. PROJECT: Improved Methods to Assess Corrosion Damage in Prestressed Concrete Beams	N
747. PROJECT: Protecting Critical Civil Infrastructure Against Impact from Commercial Vehicles – Phase I, Year 2	N
766. PROJECT: Performance of Existing ABC Projects – Inspection Case Studies (University of Nevada, Reno)	N
774. PROJECT: Development of ABC Course Module – Seismic Connections	N
842. PROJECT: TRC1903 - Investigating Concrete Deck Cracking in Continuous Steel Bridges	Y
854. PROJECT: Design Optimization and Monitoring of Joint-less Integral and Semi-Integral Abutment Bridges in Nebraska	R
14. PROJECT: FSBs with Stainless Steel Strands and GFRP Shear Reinforcement	N
40. PROJECT: SPR-4733: Steel Bridge Inspection, Assessment, Repair, and Management under FIRE	Y
41. PROJECT: Seismic Behavior of Hider Wing-Walls	N

Project Number (from the original list) and Name	Y/N
84. PROJECT: Current State of Simulated Deck Samples Cast with Corrosion Resistant Alloys (>16 years)	Y
96. PROJECT: SPR-4729: Evaluation of the Accuracy of Non-Destructive Testing (NDT) Methods for the Condition Assessment of Bridge Decks and Integration of NDT into the Asset Management Program	N
98. PROJECT: UAS-Assisted Inspection of Bridges for Corrosion Effects	N
123. PROJECT: Prediction and Prevention of Bridge Performance Degradation due to Corrosion, Material Loss, and Microstructural Changes (C21.2022)	N
136. PROJECT: Development of P-Y Curves for Analysis of Laterally Loaded Piles in Montana	N
154. PROJECT: Accelerated Sulfate Attack Testing for Concrete	Y
164. PROJECT: Pragmatic Precast/Prestressed Girder Acceptance Criteria	N
191. PROJECT: Design of Anchors for Rapid and Durable Strengthening of Bridges with Externally Bonded Carbon Fiber Reinforced Polymer Composites—Phase 2	N
208. PROJECT: ADOT Strut-and-Tie Modeling Design Guidance	N
234. PROJECT: Ultra-High-Performance Concrete (UHPC) Used as a High Friction Surface Treatment (HFST) on Pavements and Bridges	Y
237. PROJECT: Numerical Simulation of Strengthening of Bridge Decks with Partial-Depth Precast Deck Panels	N
276. PROJECT: Strut-and-Tie Design and Evaluation of Reinforced Concrete Bridge Bent Caps	N
279. PROJECT: Development of Design Recommendations for Non-Contact, Hooked Bar Lap Splices for Large Reinforcing Bars	N
284. PROJECT: Enhancing the Durability of Bridge Decks by Incorporating Microencapsulated Phase Change Materials (PCMs) in Concrete (2.16)	Y
298. PROJECT: Truck Platooning Effects on Girder Bridges, Phase II	N
304. PROJECT: Support for AASHTO Committees and Councils. AASHTO Committee on Bridges and Structures Strategic Plan, Operating Guidelines, and Research Roadmap Development	N
308. PROJECT: Seismic Performance and Fragility of Retrofitted Reinforced Concrete Bridge Columns to Long-Duration Earthquakes	N
312. PROJECT: Repairable Precast Bridge Bents for Extreme Events	N
327. PROJECT: Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement	Y
331. PROJECT: Applicability of Approximate Methods of Analysis for Skewed Straight Steel I-Girder Bridges	N
332. PROJECT: Seismic Behavior of High Strength Reinforcing Steel at Low Temperatures	N
336. PROJECT: Repairing Concrete Structures Using Near-Surface Mounted Composites with Inorganic Resins under Simulated Multihazard Damage	N
340. PROJECT: 2313 Design and Monitoring of Non-Proprietary UHPC Joints of Precast Elements	N
341. PROJECT: RES2021-14: Seismic Monitoring for Asset Management and Prioritization of Transportation Infrastructure	N
343. PROJECT: Investigation of the Benefit of Using a Novel Corrosion Resistant Steel in New and Existing Steel Bridges in Pennsylvania	N
353. PROJECT: Exploring Fiber-Reinforced Polymer Concrete for Accelerated Bridge Construction Applications	N

Project Number (from the original list) and Name	Y/N
364. PROJECT: UHPC Mixture Design for Accelerated Bridge Construction	N
390. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase IV	N
407. PROJECT: Repair or Strengthening of Bridge Decks with Partial-Depth Precast Deck Panels	N
458. PROJECT: Investigation and Assessment of Effective Patching Materials for Concrete Bridge Decks	Y
505. PROJECT: Impact of Truck Platooning on Loading of Bridges in Oregon	N
553. PROJECT: LRFR Bridge Load Rating	N
621. PROJECT: Sensor-assisted Condition Evaluation of Steel and Prestressed Concrete Girder Bridges Subjected to Fire – Phase III	N
623. PROJECT: Infrastructure Inspection During and After Unexpected Events - Phase III	N
640. PROJECT: Post-Fire Damage Inspection of Concrete Structures	N
654. PROJECT: Research for AASHTO Standing Committee on Highways. Task 428. Update of the 2012 AASHTO Guide Specification for Design of Bonded FRP Systems for Repair	N
655. PROJECT: Research for AASHTO Standing Committee on Highways. Update of the 2012 AASHTO Guide Specification for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements	N
667. PROJECT: Development of Low-Cost Multifunctional Materials for Near-Surface-Mounted (NSM) Strengthening of RC Bridge Beams and Columns	N
703. PROJECT: Reliability of Nondestructive Evaluation Methods for Bridge Decks	Y
712. PROJECT: Optimization of Advanced Cementitious Material for Bridge Deck Overlays and Upgrade, Including Shotcrete	Y
731. PROJECT: Applications of Elastomeric Polymers for Accelerated Bridge Construction and Retrofit	Y
768. PROJECT: Development of Non-Proprietary UHPC Mix (Iowa State University)	N
775. PROJECT: Performance of Existing ABC Projects – Inspection Case Studies (University of Washington)	N
796. PROJECT: RES2019-17: Concrete Bridge Deck Deterioration Assessment Using Ground Penetrating Radar	R
808. PROJECT: Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking	Y
813. PROJECT: Sustainable, Rapid Repair Using Advanced Cementitious Materials	Y
845. PROJECT: Concrete-Filled Steel Tube to Concrete Pile Cap Connections – Further Evaluation/Improvement of Analysis/Design Methodologies	N

Round 3 Rankings (79 Projects)

Project Number (from the original list) and Name	Question B Rating
46. PROJECT: Reduce Concrete Cracking through Mix Design	4.2
65. PROJECT: Alkali-Silica Reaction (ASR) Mitigation in High Alkali Content Cements	4.2
44. PROJECT: Evaluate Bridge Deck Condition and Replacement Methods	3.8
177. PROJECT: Mitigation Strategies for Cracking in Concrete Bridge Decks	3.8
155. PROJECT: Alkali-Silica Reaction Mitigation using Alternative Supplementary Cementitious Materials	3.7
8. PROJECT: Implementation of Bridge Preservation Actions	3.4
25. PROJECT: Computer Vision Tools for Bridge Inspections and Reporting	3.4
761. PROJECT: Precast Pier System for Accelerated Bridge Construction in Idaho	3.3
73. PROJECT: Durability and Volumetric Stability of Non-Proprietary Ultra High Performance Concrete Mixes Batched With Locally Sourced Materials	3.2
48. PROJECT: Establishing NDE Protocols for Use in Early Age Bridge Deck Preservation Strategies	3.2
858. PROJECT: Evaluation of Bridge Rail Systems to Confirm AASHTO MASH Compliance	3.0
67. PROJECT: Construction of Low-Cracking High-Performance Bridge Decks Incorporating New Technology	3.0
37. PROJECT: Significant Factors of Bridge Deterioration	3.0
555. PROJECT: Development of Deterioration Curves for Bridge Elements in Montana	3.0
51. PROJECT: Improved Beam End Reinforcement Details for PCBTs with Debonded and/or Draped Strands	3.0
808. PROJECT: Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking	2.8
337. PROJECT: Data-Driven Decision-Making Framework for Inspection of Bridge Decks	2.8
9. PROJECT: Low-Cement Concrete (LCC) Mixtures for Bridge Decks and Rails	2.8
154. PROJECT: Accelerated Sulfate Attack Testing for Concrete	2.8
114. PROJECT: Repair and Strengthening of Bridge Girders Using Ultra-High-Performance Concrete (UHPC)	2.8
47. PROJECT: SPR-4718: Influence of Nanomaterials-based Admixtures on the Entrained Air Void System and Freeze-Thaw (FT) Resistance of Concrete	2.8
567. PROJECT: Effectiveness of Concrete Bridge Deck Sealants	2.7
813. PROJECT: Sustainable, Rapid Repair Using Advanced Cementitious Materials	2.7

Project Number (from the original list) and Name	Question B Rating
99. PROJECT: Evaluation of Multi-Layer Polymer Concrete Overlays	2.7
458. PROJECT: Investigation and Assessment of Effective Patching Materials for Concrete Bridge Decks	2.7
583. PROJECT: Evaluation of Thin Polymer Overlays for Bridge Decks	2.6
676. PROJECT: Evaluating Integral Abutment Performance	2.6
80. PROJECT: Mitigating Cracks in Concrete Members for Durable Bridge Construction	2.6
78. PROJECT: Capacity Prediction of Repaired and Unrepaired Bridge Beams with Deteriorated Ends	2.6
703. PROJECT: Reliability of Nondestructive Evaluation Methods for Bridge Decks	2.5
668. PROJECT: Field Implementation and Monitoring of an Ultra-High Performance Concrete Bridge Deck Overlay	2.5
726. PROJECT: Performance Evaluation of Polyester Polymer Concrete Overlays Continuation Proposal Phase II TR-772	2.5
788. PROJECT: Fiber-Reinforced Concrete in Bridge Decks TR-767	2.5
506. PROJECT: Alternative High Early Strength Concrete (HESC) Structural Overlays	2.4
54. PROJECT: Reducing the Cost and Facilitating Broader Adoption of Ultra-High-Performance Concrete (UHPC) in Bridges	2.4
330. PROJECT: Performance of Cost-Effective Non-Proprietary UHPC in Thin Bonded Bridge Overlay	2.4
712. PROJECT: Optimization of Advanced Cementitious Material for Bridge Deck Overlays and Upgrade, Including Shotcrete	2.3
40. PROJECT: SPR-4733: Steel Bridge Inspection, Assessment, Repair, and Management under FIRE	2.3
143. PROJECT: Experimental Validation of Repair Methods for Earthquake-Damaged Bridges Incorporating ITD's Precast Pier System	2.3
494. PROJECT: Fiber Reinforced Concrete Overlays for Bridge Structures	2.2
715. PROJECT: UHPC Thin Bonded Overlay on Deteriorated Bridge Decks	2.2
36. PROJECT: Use of Fiber-Reinforced Polymer Composites for Bridge Repairs in Montana	2.2
434. PROJECT: Rehabilitation of Deteriorated Bridge Decks with Ultra-High Performance Concrete Overlays	2.2
816. PROJECT: Development and Testing of High / Ultra-High Early Strength Concrete for durable Bridge Components and Connections (2.5)	2.2
196. PROJECT: Fiber Reinforced Concrete (FRC) Beam End Repairs for Corroded Steel Beam Ends	2.2
68. PROJECT: Performance Evaluation of Reinforced Concrete Box Culverts	2.2
646. PROJECT: 2287 Evaluation of the Expected Life and Recoating of Silane Water Repellant Treatments on Bridge Decks	2.2
387. PROJECT: Assessment and Repair of Prestressed Bridge Girders Subjected to Over-Height Truck Impacts (OHTI)	2.0
32. PROJECT: High Bond Steel Fibers for Ultra High Performance Concrete (UHPC)	2.0

Project Number (from the original list) and Name	Question B Rating
234. PROJECT: Ultra-High-Performance Concrete (UHPC) Used as a High Friction Surface Treatment (HFST) on Pavements and Bridges	2.0
84. PROJECT: Current State of Simulated Deck Samples Cast with Corrosion Resistant Alloys (>16 years)	1.8
132. PROJECT: Develop Countermeasure Strategies for Protecting Bridge Girders Against Overheight Vehicles Impact	1.8
535. PROJECT: Guide to Remediate Bridge Deck Cracking	1.8
147. PROJECT: Designing and Characterizing New Coating Materials to Increase the Corrosion Resistance of Steel Reinforcement Embedded in Concrete	1.8
227. PROJECT: 2292 Innovative Multi-Hazard Resistant Bridge Columns for Accelerated Bridge Construction	1.8
758. PROJECT: Assessment of Asbestos Containing Materials in Idaho Bridges	1.7
842. PROJECT: TRC1903 - Investigating Concrete Deck Cracking in Continuous Steel Bridges	1.7
66. PROJECT: Laboratory Characterization of Fiber-Reinforced Polymer Rein. Material Properties and Surface Treatment Behavior in Concrete	1.7
284. PROJECT: Enhancing the Durability of Bridge Decks by Incorporating Microencapsulated Phase Change Materials (PCMs) in Concrete (2.16)	1.7
369. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	1.6
381. PROJECT: Performance of Prestressed Bridge Girders Subjected to Vehicle Impacts	1.6
282. PROJECT: Exploration of UHPC Applications for Montana Bridges	1.6
731. PROJECT: Applications of Elastomeric Polymers for Accelerated Bridge Construction and Retrofit	1.6
241. PROJECT: Identification of Maintenance Practices to Impede Corrosion Impacts on Prestressed Concrete Box Beam Bridges	1.6
101. PROJECT: Legal Truck Load Ratings for Standard Reinforced Concrete Boxes and Rigid Frame Boxes for HL-93 Loading	1.6
773. PROJECT: Development of Non-Proprietary UHPC Mix – Evaluation of the Shear Strength of UHPC (University of Washington)	1.5
86. PROJECT: The Influence of Vehicular Live Loads on Bridge Performance	1.4
563. PROJECT: Assessment, Repair and Replacement of Bridges Subjected to Fire	1.4
585. PROJECT: Durability Assessment of Externally Bonded FiberReinforced Polymer (FRP) Composite Repairs in Bridge	1.4
569. PROJECT: Reliability of ABC Grouted Coupler Connected Bridge Piers Subject to Vehicular Impact	1.4
327. PROJECT: Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement	1.4
630. PROJECT: Cost-effective Bridge Decks for Improved Durability and Extended Service Life	1.4
559. PROJECT: Long-term Performance of HES Class 50AF Concrete with Polypropylene Fibers as Field-Cast Connection between Deck Bulb-T Girders in SH-36 Bridge over Bear River	1.3
144. PROJECT: Stainless Steel Coated Rebar for Chloride Resistant Concrete Highways and Bridges	1.2

Project Number (from the original list) and Name	Question B Rating
221. PROJECT: Ultra-High Performance Concrete Connections Between Precast Bridge Deck Elements	1.2
501. PROJECT: Fatigue Life Analysis of Reinforced Concrete Beams Strengthened with Composites	1.2
297. PROJECT: SPR-4532: Synthesis Study: Repair and Durability of Fire Damaged Prestressed Concrete Bridge Girders	1.0
532. PROJECT: Performance of ABC Columns and Cost-Effective Retrofit Strategies Subjected to Synergistic Distress Resulting From Corrosion and Seismic Loading	1.0
138. PROJECT: Post-Fire Damage Inspection of Concrete Structures - Phase III - In-Situ Experimental Phase	1.0

Appendix B. Summary of DOT Survey Questionnaire Responses

Introduction

Below is a summary of Department of Transportation (DOT) responses to the survey questionnaire sent by ITD Research Program Manager. There were 21 responses from the following states: Arizona, Arkansas, Colorado, Delaware, Iowa, Kentucky, Minnesota, Mississippi, Missouri, Montana, Nebraska, New Jersey, North Carolina, Oklahoma, South Dakota, Tennessee, Texas, Utah, Vermont, Washington, and Wyoming. Many responses did not directly answer the questions or parts of the answers were missing.

Survey Questions and Corresponding Responses

Question 1: What are the focus areas or priority topics for current and future bridge research at your DOT? Why are you focusing your efforts in these areas?

Arizona: Bridge Design, Bridge Materials and Preservation.

Arkansas: Some areas of focus are use of uncoated weathering steel for superstructure elements. We have a relatively high inventory of weathering steel bridges and have noticed corrosion issues on some of the bridges.

Colorado: Recent research focus areas include bridge rail, asset management, and bridge repairs. New MASH standards drove the focus on bridge rail, and an aging infrastructure plus a mostly static budget has driven the focus on asset management and bridge repairs.

Delaware: We conduct research on an ad hoc basis where we initiate research projects based on specific problems or questions we need answers to. We also participate in pooled fund studies when there is a topic of interest.

Iowa: (a) Bridge preservation: We have an aging infrastructure and Iowa DOT is more focused on steward of existing assets than expansion. We want to make informed decisions that have the Least Lifecycle Cost. (b) BIM/Digital delivery: Iowa DOT recognizes the potential benefits of BIM/digital delivery for bridge projects for internal and downstream customers within and outside the DOT. (c) UHPC: The properties of the material lend itself to structures that have reduced lifetime maintenance cost and improved safety for the public, contractors and employees who preform bridge maintenance. (d) Load Rating: Load Rating has become more of a concern the past 7-10 year with frequent changes to State and Federal legal permit loads. Many state bridges were designed below current design standards and we need to ensure with increased loading the bridge are still safe for the traveling public.

Kentucky: Metrics to prioritize bridges for potential projects, use of known loads and strain gages to aid in load rating bridges that have unknown plan sets, guidance on Spot and Zone Painting, a steel bridge Inventory and developed training for bridge preservation project inspection (concrete sealers, grease bearing, deck overlays).

Minnesota: Current research projects that are underway: Develop Element Level Bridge Performance Measures and Targets, Understanding Causes of Concrete Culvert Pipe Joint Separation, Assessing the Need for Floodplain Culverts Based on Geomorphology, Ice Loading on Piers for Minnesota's Bridges, Correlation Between Deck Patching Quantities and Chloride Concentration Levels, Understanding Driving Causes of Bridge Replacement, Deck Reinforcement Detailing and Concrete Mix Additives to Reduce Bridge Deck Cracking, Vehicle-Based Ground Penetrating Radar (GPR) System Evaluating Rebar Cover on 198 Minnesota Bridges, Precast vs. Cast in Place Box Culverts.

Mississippi: We have been focusing on prestress beams and seismic design. We are trying to identify areas we can refine or modify our design approach and achieve as good or better long-term results.

Missouri: Our research generally follows our current needs. We don't necessarily have focus areas, but reviewing our recent research projects we are focusing primarily on construction and bridge preservation.

Montana: UHPC applications including deck overlays, joints, and non-proprietary mixes. FRP applications focusing on best practices, and potentially timber girder repairs. Steel pile-to-pile cap connections – 2/3 sized testing and design. Feasibility study of Road Culverts/Bridge Deck deicing using geothermal energy. Significant Factors of Bridge Deterioration. Evaluation of thin polymer overlays for Bridge Decks.

Nebraska: Priority topics are to continue with our roadmap goals for UHPC (see attached), Preservation topics such as improving GPR NDT Inspection to be more useful when inspecting bridge with AC + waterproof membrane which is NDOT standard bridge preservation Overlay, Optimize Nebraska bridge deck concrete mix to achieve less shrinkage cracking by using less cement content. Also, we are experimenting using Internal curing cement.

New Jersey: (a) Safety, durability, resilience, and knowledge gaps, such as MASH implementation, weigh-in-motion, seismic and multi-hazard design, scour analysis, field monitoring of bridges and retaining walls, orthotropic steel decks, concrete decks, etc. which are all from practical needs of bridge design and construction. (b) High-performance internal curing concrete – Bureau of Research is currently conducting a research project on HPIC. Extensive research has already been performed by other agencies and institutions, Bridge Division will not be conducting additional research, but is actively developing pilot projects.

North Carolina: Current focus is on three areas; first is the use of innovative materials that provide resiliency, second is preservation activities/materials that increase structure lifecycles, and the third is asset management tools for programming structure preservation and/or replacements projects.

Oklahoma: Prestress, UHPC, Dynamic impact factor, Temperature effects, Load rating, rebar corrosion.

South Dakota: Bridge approach smoothness, bridge deck sealants, pile load testing. These are the current priorities of SDDOT.

Tennessee: We have research efforts centered around seismic impacts on our bridge network, local UHPC, load rating, and pile performance and steel pile protection methods. We do research on areas that show repeated impacts on out bridge network or whose results can lower our risk exposure to certain events.

Texas: Preserving assets, durability, increased speed of construction, new technologies (3D modeling, digital delivery, strengthening or rehabilitating current assets, etc.), refined design and evaluation methods (re-examining minimum reinforcement requirements for shear design in prestressed members), maintenance (designing bridges that calls for less maintenance and inspection), safety improvements.

Utah: Fiber Reinforced Concrete Bridge Decks. Bridge Deck Construction Research. Chloride Ion Ingress in Concrete Bridge Decks and Parapets. Lightweight Concrete Bridge Decks. Early Degradation in Bridge Deck Concrete. Bridge Decks with Partial-Depth Precast Deck Panels. Differential Settlement at Highway Bridge Approaches. Reinforced and Unreinforced Lightweight Cellular Concrete for Retaining Walls.

Vermont: Focus areas change according to Agency needs. We have so few research $ and can select so few projects, what gets matched to Champions is based on what our Champions think is important that year.

Washington: Seismic resiliency and resiliency in general for bridge structures are likely to remain a high priority for WSDOT. This is because western WA falls in a high-risk subduction zone and resiliency of our infrastructure is one of our WSDOT's strategic goals.

Wyoming: Internal curing concrete. Wyoming struggles to maintain optimum placement conditions with our low humidity and frequent winds - our hope is to help mitigate some of these issues with internally cured concrete.

Question 2: What research completed in the last 5 years has had the most impact on your state DOT's bridge program? What was implemented and what benefits resulted from these projects?

Arizona: Bridge Materials research with Ultra-High Performance Concrete, though not implemented, the research has provided additional knowledge to potentially pursue in the future.

Arkansas: ARDOT has recently began investing more into preservation, maintenance and rehab of bridges. It may not be new research but learning best management practices from other DOT's had led to us utilizing more polymer overlays, hydro-demolitions, etc. when managing our bridge inventory.

Colorado: MASH rail - Updated a bridge rail design to meet MASH standards. Timber bridge repair - developed a methodology for rating timber bridges with a newly implemented repair for split timber girder superstructures. Bridge deterioration models - using machine learning to develop deterioration models for bridges.

Delaware: We performed a synthesis of jointless bridges to help better understand best practices for this type of detail after poor performance of some details used on a corridor project. We also recently completed a study of performance of different types of overlay materials over concrete and UHPC substrates with different surface preparation practices. Both of these were examples of specific issues we had on projects/programs and resulted in spec or detail changes. We also participated in the recently completed pooled fund study led by Ohio DOT related to structural liners of buried culverts.

Iowa: (a) ABC research – there were a whole variety of pilot projects and lab tests that led to the pile pocket connection and our current ABC practices. We learned each step of the way and are fairly settled into lateral bridges slides now. (b) The UHPC research is similar to the ABC research in lots of pilots and tests to lead to routine implementation but maybe not quite as far along. The development of the non-proprietary UHPC mix I think was a big step that was recently completed and there is current work on a non-proprietary UHCP overlay mix. (c) The PPC beam camber research seemed influential with our current practices and the reduction factor. (d) We have done quite a bit with mass concrete that led to improvement of our specifications and of the ConcreteWorks program.

Kentucky: No specific response was given, only a general response for Question 1.

Minnesota: Due to the large number of projects it's difficult to select just a few that had the most impact, but here are a few that were very beneficial: the use of unmanned aircraft systems (UAS) to conduct bridge inspections, re-tightening large anchor bolts of support structures for signs and luminaires, anchorage of epoxy-coated chemical adhesives, debonded strands in prestressed concrete bridge girders, and review and assessment of past MnDOT bridge barrier types, to name a few.

Mississippi: We completed a study comparing design cambers vs. field measured cambers. While there are formulas to determine prestress beam cambers, the final cambers that occur in the field are based on in-field concrete data and not design values. The research gathered data from a couple years' worth of projects. We were able to use the data to modify formula values to help the calculated design values to better line up with what we are seeing in the field. This should help reduce construction issues of extra haunch thicknesses and grade modifications.

Missouri: I don't see a recent research project that has had a huge effect on our program. This may be partially due to lack of resources to fully implement research recommendations.

Montana: Developed a non-proprietary Ultra High-Performance Concrete (UHPC) and implemented on two Montana bridges for critical bridge connections and joints. The joints have outperformed other grouts and concretes used in other bridges.

Nebraska: Last research was very useful is Developing Nonproprietary UHPC mix for plant and cast in place use in addition to Nebraska family of UHPC Decked I beam (NDIB) standard.

New Jersey: (a) Enhance the NJDOT's Structural Management Activities (bridge deterioration curves, data mining and technical assistance for bridge and structural asset management systems, Life Cycle Cost Analysis within bridge management system (BMS), Risk Based Prioritization (RBP) work, Research in accordance with map 21 requirements, Develop guide document for preservation, deterioration, life cycle-cost and prediction models for ancillary structural assets. Research and innovate bridge predictive modeling methods for assessing bridge preservation best practices using AASHTOWare products). (b) Structural Load Capacity Analysis. (c) Innovative Material and Technology (Rapid Set Materials, Polyester Polymer Concrete, Structural Adhesives).

North Carolina: The research project done in the past 5 years with the most impact for today has been a project that utilizes a repair system that can be rapidly installed by NCDOT maintenance crews to provide structural capacity until a bridge can be programmed for replacement. This system has been utilized several times now in NC and has allowed those bridges to remain open to the traveling public for a year or more while NCDOT has programmed their replacements.

Oklahoma: Rebar corrosion study.

South Dakota: We haven't had completed bridge research in the past 5 years with implementation in place long enough to see the benefits.

Tennessee: We did research on approach slab settlement and best practices to remedy the issue. To date, the revisions to our construction practices with approach slab installations have yielded positive results.

Texas: Listed projects without identifying which ones had the "most impact". The bridge research were: (1) Bridge Strengthening Design and Load Testing for a Continuous Steel Girder Bridge with Post Installed Shear Connectors, (2) Partial Depth Precast Concrete Deck Panels on Curved Bridges, (3) End Region Behavior of Pretensioned Concrete Beams with 0.7-inch Prestressing Strands, (4) Develop Strong and Serviceable Details for Precast, Prestressed Concrete Bent Cap Standards that can be implemented on everyday bridge construction projects, (5) Strengthening of Existing Inverted-T Bent Cap Ledges, (6) Evaluate Specialized Hauling Vehicles with regard to pavement and bridge deterioration and posting limits, (7) Designing for Deck Stress over Precast Panels in Negative Moment Regions, (8) Seismic Vulnerability and Post-Event Actions, (9) Integral Semi-integral Abutments and Implementation to TxDOT Bridges, (10) Establishing Comprehensive Manual on Assessing Safety Hardware (MASH) Compliance for Roadside Safety Systems in Texas, (11) Single Slope Concrete Barrier (54" tall) on a Structurally Independent Foundation, (12) Evaluating Bridge Behavior using Ultra-High Resolution Next-Generation Digital Image Correlation(DIC): Applications in Bridge Inspection and Damage Assessment, (13) Strut-and-Tie Modeling and Design of Drilled Shaft Footings, (14) Calibration of Bridge Element Based Deterioration Models (Developing Deterioration Rates of Texas Bridges Using NBI Data).

Utah: Polyester Polymer Concrete for Bridge Deck Overlays. Bridge Deck Chloride Testing Protocols. Influence of Wingwall Geometry and Skew Angle on Passive Force Behavior of Bridge Abutments from Large-Scale Testing.

Vermont: No specific response was given other than this statement: "All of these have had some impact in Vermont. Benefits are mixed. Our bridge engineers are happy to experiment with new materials …"

Washington: Use of Hollow Prestressed Concrete Pile-Columns for Bridges in Seismic Regions. Effects of Cascadia Subduction Zone M9 Earthquakes on Bridges in Washington State. Performance of Steel Jacket Retrofitted Reinforced Concrete Bridge Columns in Cascadia Subduction Zone Earthquake. Safety of Long Girders During Handling and Transportation: Lateral Stability and Cracking.

Wyoming: No specific response was given. Only provided a list of projects, presumably the projects that were funded in the last five years.

Question 3: What process does your bridge program follow for identifying and prioritizing bridge research needs?

Arizona: Collaboration with ADOT Staff, Universities and Industry Professionals.

Arkansas: We do not have a formal process. There are multiple sections/divisions/districts that are concerned with bridge maintenance and construction issues. Based on the issue and needs we discuss what research should be prioritized.

Colorado: To my knowledge, we have no formal process. Needs are identified throughout the year as issues arise and prioritized based on perceived benefit to CDOT.

Delaware: Discussion among myself (Chief of Bridges and Structures) and the 3 group managers (Design, Management, and Maintenance/Construction). We generally only have 1-2 research topics at a time so there is rarely any prioritization among bridge research needed.

Iowa: The Bridges and Structures Bureau has an annual meeting with the focus of discussing research needs. Other Bureaus including Construction and Materials, Research and Analytics and some researchers are invited and research ideas that affect bridge are proposed, discussed, and prioritized. Ideas that do not make it through this year can be carried forward to next year meeting.

Kentucky: No response was given.

Minnesota: The MnDOT Office of Research & Innovation hosts an open solicitation seeking research needs with final ideas/needs due in March of each year. A committee of area experts from the Bridge Office and districts review and prioritize the bridge & hydraulics related ideas.

Mississippi: Our research is typically in response to issues we are seeing in the field. We are either trying to modify our design to alleviate the issue or we are trying to save construction time and costs.

Missouri: There is no process. We have yearly meetings with our research partners to discuss potential research needs.

Montana: Typically, informal methods involving communication between bridge and asset owners, researchers, and bridge engineers leads us to research. Typically, the successful research projects are selected because they address problem areas identified in the aging bridge inventory.

Nebraska: Nebraska collaborate with the university of Nebraska academia on all level. We have open communication that the researches can present their ideas, and we present our needs based on yearly meeting to meet short and long term needs and strategy.

New Jersey: Research for future improvements and benefits to structures (improved durability, reduced maintenance, increased service life, increased safety for public, simplify construction techniques).

North Carolina: NCDOT's Research Unit provides information on how projects are identified and prioritized on their website: https://connect.ncdot.gov/projects/research/Pages/default.aspx

Oklahoma: Ranking the different research projects.

South Dakota: Bridge research needs are lumped in with other research needs in the department when it comes to prioritizing.

Tennessee: We actively participate in AASHTO CBS TC's and will gather topics for research based on those national discussions with the research slanted toward TDOT specific applications or TN based materials or environment.

Texas: TxDot breaks our research topics into five areas of expertise. One area is called Structures and Hydraulics (S&H), which encompasses bridge related research. We start every research cycle by collecting ideas and distributing the ideas to the appropriate group, so bridge related ideas go to the S&H group. The experts in S&H vote on all the S&H project ideas to determine what is of greatest need. We fund and manage the projects with the highest expressed need. This is a bit of an oversimplification of the process, but many layers of experts must agree on the need before we move forward to RFP the idea.

Utah: The bridge program prioritizes research outcomes which are immediately implementable with a focus on preserving infrastructure. In recent years we have been working toward durability goals with concrete materials.

Vermont: We are interested in current needs matched with a technical Champion. If a Champion is energized, the project is included in our process and Bureau Director level managers choose the projects that are most important to AOT.

Washington: Bridge SMEs identify and prioritize needs within WSDOT's Bridge & Structures office and develop proposals internally or in conjunction PI's from universities that have the expertise and facilities in these areas. Usually, the top 2-3 proposals are then forwarded to the WSDOT Research office for consideration every biennium to "compete" for selection and funding through the SPR program.

Wyoming: Current issues - Our program may see common issues that need to be investigated further. Design implementation to ensure future compliance - Future MASH compliance. Bridge Management System - Our program relies heavily upon our BMS - which will help guide our future resource as we may see more bridge replacements in the future compared to rehabilitation.

Question 4: Please estimate the percentage of funding for current bridge research in your agency that is allocated to each of the following bridge component categories:

____deck ____superstructure ____substructure ____railing ___other (please specify: ________)

Responses to Question 4: Several did not respond or provided incomplete responses. For example, in a few responses the percentages did not add to 100%. The chart below shows the average percentage responses in each category for those that provided complete/correct responses.

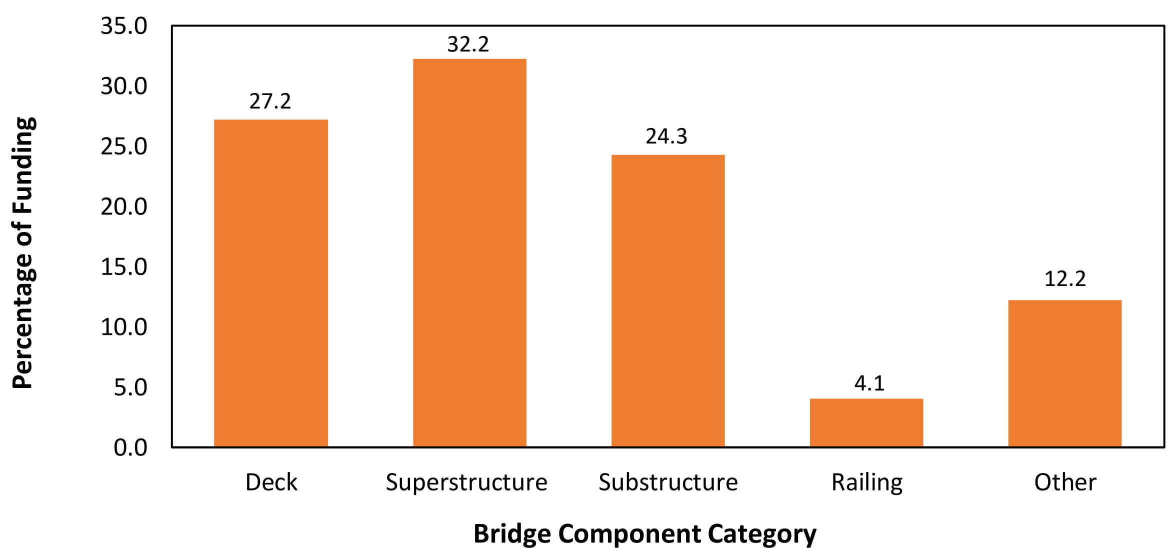


Figure B.1 Average percentage responses in each category for those that provided complete/correct responses.

Question 5: Please estimate the percentage of funding for current bridge research in your agency that is allocated to each of the following bridge program activities:

_____design _____construction _____preservation _____inspection _____load rating ____other (please specify: ________)

Responses to Question 5: Several did not respond or provided incomplete responses. The chart below shows the average percentage responses in each category.

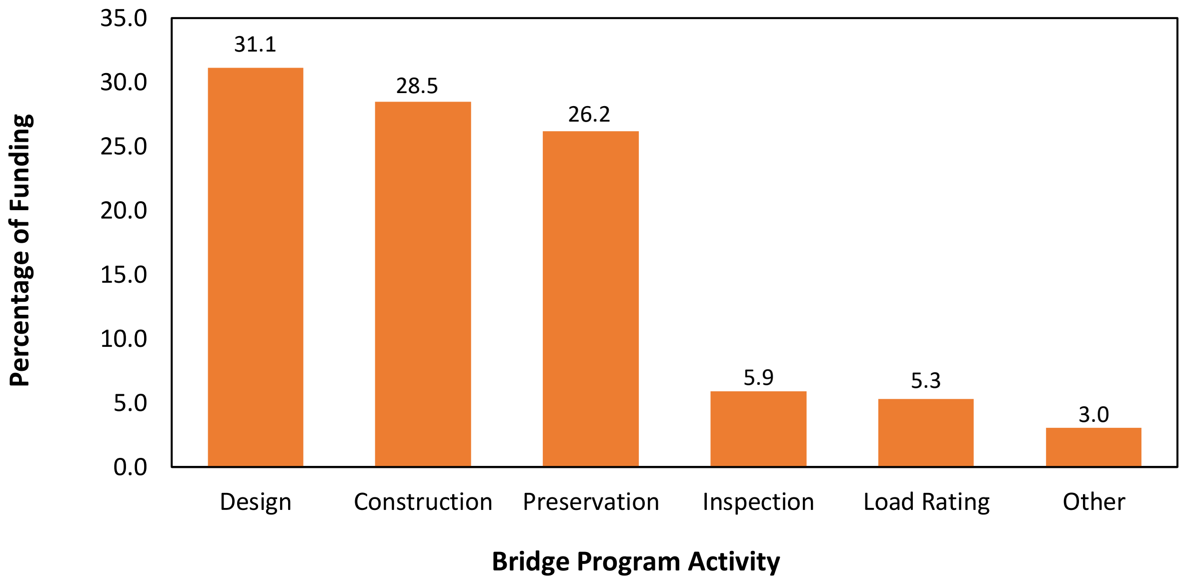


Figure B.2 Average percentage response for each category.

Question 6: What percentage of the current bridge research funding in your agency supports bridge-related Transportation Pooled Fund projects?

Responses to Question 6: From those that provided specific percentages, the average percentage is approximately 16%. For details of responses, see below.

Arizona: Currently, the Arizona DOT is not committed to any Transportation Pooled Fund projects that support Bridge efforts.

Arkansas: About 10% goes to Pooled Funds. We currently participate in one bridge-related TPF, TPF-5(486) Center for the Aging Infrastructure: Steel Bridge Research, Inspection, Training and Education Engineering Center – SBRITE.

Colorado: 20%

Delaware: We are active in a couple of pooled fund studies – BIM for Bridges and Structures (Iowa DOT) and Hybrid Steel Girders(NCDOT). These comprise about 50% of what we spend annually on bridge research.

Iowa: 30%

Kentucky: No response given.

Minnesota: Sorry, the Bridge Office competes with MnDOT other offices for research funding (does not get its on allocation) so I don't have access to the funding information.

Mississippi: 35%

Missouri: 10%

Montana: 6.4%

Nebraska: No response given.

New Jersey: No response given.

North Carolina: 5%

Oklahoma: 7%

South Dakota: 0%

Tennessee: 1%

Texas: No percentage given.

Utah: 50%

Vermont: … VT AOT participate in very few Pooled Funds. We currently participate in the Bridge Information Monitoring for Bridges and Structures Pooled Fund led by Iowa DOT. That fund is finishing Phase I and we plan to join Phase II. Research funds also pay for the bridge-related Technical Service Programs, Structures Guidelines and Preservation Management and our bridge folks are heavily involved in these.

Washington: This changes from biennium to biennium depending upon the research priorities in other areas. For this biennium (Jul 2023-Jun 2025) about 10% of the total funding allocated to the P/F program is reserved for Bridge & Structures research.

Wyoming: 1.5%

The chart below shows the percentage of the current bridge research funding in the DOTs that provided response supporting bridge-related Transportation Pooled Fund projects.

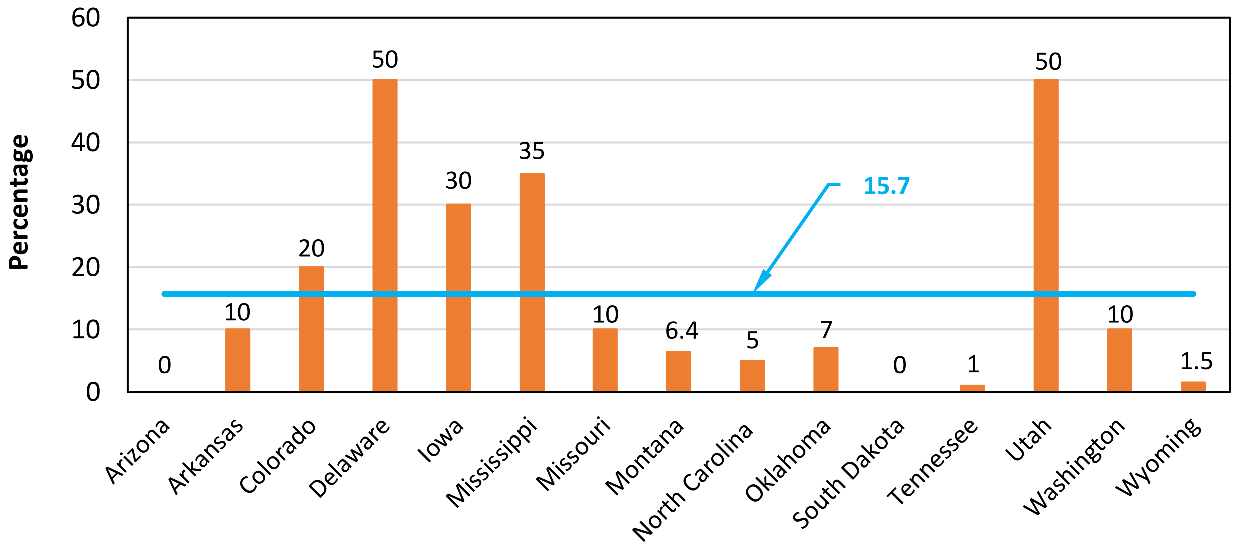


Figure B.3 Percentage of current bridge research funding in the DOTs that provided responses supporting bridge-related Transportation Pooled Fund projects.

Question 7: Please provide the name, title, and contact information for the staff person completing this survey.

Responses to Question 7: Everyone provided names, email addresses, etc.

Appendix C. Idaho's Deficient Bridge General Data

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
30925	NUCKOLS GULCH ROAD	I 90;NUCKOLS GULCH RD GS	1	Prestressed Concrete	Stringer/Girder	4	66	212	1969	0	0	0	N
30510	S ANDERSON LAKE RD	CD'A RIVER;SPRINGSTON BR	1	Steel	Truss-Thru	1	120	302	1955	1	6	1	N
30130	GROUSE CK; NF 280	GROUSE CREEK	1	Prestressed Concrete	Tee Beam	1	51	54	1974	3	3	4	N
30735	FIFTH STREET	S.FK.COEUR D'ALENE RIVER	1	Steel	Stringer/Girder	1	34	35	1972	3	4	5	N
20575	STC 5758;6TH ST	S.FK.CDA RIVER:6TH ST.	1	Concrete	Tee Beam	1	35	37	1916	4	4	2	N
30960	MILL ROAD	I 90;MILL ROAD IC	1	Concrete	Tee Beam	6	41	240	1963	4	4	4	N
30520	STC5751;OLD HWY 95	SIRR & UPRR;S.ATHOL OP	1	Concrete	Tee Beam	6	37	181	1929	4	4	5	N
17315	I 90 EBL & WBL	RR ROADBED/NO TRACKS	1	Concrete Continuous	Single/Spread Box	3	100	256	1972	4	4	6	N
30765	BUNKER AVE	S.FK.COEUR D'ALENE RIVER	1	Prestressed Concrete	Channel Beam	3	89	168	1971	4	4	6	N
30805	PINE DRIVE; NF 301	W.FK.ST MARIES RIVER	1	Steel	Stringer/Girder	1	30	30	1973	4	5	5	N
37080	OLD MIL. RR GRADE	SLOUGH BRIDGE	1	Wood or Timber	Stringer/Girder	6	16	97	1912	4	6	4	N
30830	LOWER GEM HILL RD	CANYON CREEK;GEM BR	1	Steel	Stringer/Girder	1	35	41	1982	5	4	2	N
30315	S5907;DEEP CRK LP	BNRR;UPRR & DEEP CREEK	1	Steel	Truss-Thru	1	161	502	1936	5	4	5	N
30280	DEER CREEK ROAD	SKIN CREEK	1	Wood or Timber	Stringer/Girder	1	27	29	1960	5	5	4	N
30300	WILDERNESS ROAD	DEEP CREEK;SHILO BRIDGE	1	Wood or Timber	Stringer/Girder	1	38	39	1960	5	5	4	N
30785	OLD RIVER ROAD	STC 5752;N.FK.CD'A RIVER	1	Steel	Truss-Thru	1	150	264	1930	5	5	4	N
30994	POTLATCH ROAD	AGATHA CREEK TRESTLE	1	Wood or Timber	Stringer/Girder	8	14	112	1912	5	5	4	N
30996	POTLATCH ROAD	BLACK PRINCE TRESTLE	1	Wood or Timber	Stringer/Girder	10	14	140	1912	5	5	4	N
30992	POTLATCH ROAD	ELK CREEK TRESTLE	1	Wood or Timber	Stringer/Girder	6	14	85	1912	6	3	3	N
30120	EAST RIVER LOOP	N.FK.EAST RIVER	1	Steel	Truss-Thru	1	120	122	1939	6	4	3	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
30225	RAPID LIGHTNING RD	RAPID LIGHTNING CREEK	1	Wood or Timber	Stringer/Girder	1	39	41	1970	6	4	5	N
30590	STC 1699;CANYON RD	COEUR D'ALENE RIVER	1	Steel	Truss-Thru	1	250	328	1936	6	4	5	N
10090	SH 3	ST MARIES RIVER	1	Concrete	Tee Beam	3	34	105	1955	6	5	3	N
20404	STC 5711;MOON PASS	BIG DICK CREEK	1	Steel	Stringer/Girder	4	64	239	1909	6	5	3	N
37085	OLD MIL. RR GRADE	TROUT CREEK	1	Steel	Stringer/Girder	1	39	89	1912	6	5	3	N
30090	CHARLIE CREEK RD	SANTA CREEK	1	Wood or Timber	Stringer/Girder	1	22	25	1964	6	5	4	N
37835	COOPER PASS ROAD	CANYON CREEK	1	Steel	Stringer/Girder	1	30	38	2012	6	6	2	N
30140	MID. FK. EAST R RD	N.FK.EAST RIVER	1	Concrete	Tee Beam	1	23	24	1974	6	6	3	N
30245	E SHORE ROAD	HUNT CREEK	1	Prestressed Concrete	Tee Beam	1	23	24	1975	6	6	3	N
33575	NORTHWEST PASSAGE	SKI TRAIL	1	Prestressed Concrete	Tee Beam	1	54	55	1995	6	6	3	N
20645	S5786;COLBURN CULV	GROUSE CREEK	1	Steel	Stringer/Girder	1	61	65	1941	6	6	4	N
30235	COLBURN CULVER RD	PACK RIVER	1	Steel	Stringer/Girder	1	75	96	1941	6	6	4	N
30655	THIRD STREET	S.FK.COEUR D'ALENE RIVER	1	Steel	Stringer/Girder	1	28	32	1978	6	6	4	N
30810	NORTHSIDE RD	BLACK PRINCE CREEK	1	Wood or Timber	Stringer/Girder	1	31	33	1965	6	6	4	N
10010	US 2	PRIEST RIVER	1	Prestressed Concrete	Stringer/Girder	7	50	352	1962	6	7	4	N
16820	I 90 WBL	PEDESTRIAN/BIKE PATH	1	Prestressed Concrete	Stringer/Girder	3	44	130	1971	6	8	4	N
20695	STC 5804;WESTSIDE	MYRTLE CREEK	1	Wood or Timber	Stringer/Girder	1	50	52	1958	7	6	4	N
30491	LOFFS BAY ROAD	MICA CREEK	1	Steel	Stringer/Girder	1	35	35	2006	7	6	4	N
30345	RUBY CREEK RD	RUBY CREEK(#4)	1	Steel	Stringer/Girder	1	23	24	1970	8	6	4	N
17250	I 90B	S.FK.CD'A R;I-90B ARCH	1	Concrete	Culvert	1	94	94	1940	N	N	N	4
10560	SH 13B	M.F.CLWATER R.;E.KOOSKIA	2	Steel	Truss-Thru	3	122	481	1935	4	4	5	N
29965	LENORE GRADE ROAD	CLEARWATER R;LENORE BR.	2	Steel	Girder-Floorbeam	1	160	526	1935	4	5	4	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
29595	LITTLE BEAR ROAD	BIG BEAR CREEK	2	Steel	Stringer/Girder	1	45	46	1959	5	5	4	N
29785	ACCESS RD; PARK RD	LAWYERS CREEK;PARK BR	2	Steel	Truss-Thru	1	60	63	1917	5	6	4	N
29850	MCINTYRE STREET	LAPWAI CREEK	2	Steel	Stringer/Girder	2	35	61	1935	6	6	2	N
14925	SH 162	SEVEN MILE CREEK	2	Concrete	Frame	1	31	31	1949	6	6	4	N
29230	COUNTY ROAD	N.FK.SKOOKUMCHUCK CREEK	2	Wood or Timber	Stringer/Girder	1	23	24	1965	7	6	4	N
29050	MAIN STREET SOUTH	JIM FORD CREEK	2	Steel Continuous	Stringer/Girder	2	25	52	1965	7	7	2	N
29220	LONGHAUL ROAD	COTTONWOOD CREEK	2	Steel	Stringer/Girder	1	29	30	1960	8	8	4	N
26795	ROSE GARDEN RD	NOTUS CANAL	3	Wood or Timber	Stringer/Girder	1	48	51	1935	4	4	4	N
28317	SHEEP CAMP RD	GRANDVIEW IRRIGATION CNL	3	Wood or Timber	Tee Beam	1	25	26	1991	4	4	7	N
28915	RIVER ROAD	DIXIE CREEK	3	Steel	Truss-Thru	1	60	63	1917	4	5	3	N
19855	STC 3805;SIMCO RD	I 84;BASELINE SIMCO IC	3	Prestressed Concrete	Stringer/Girder	3	49	212	1960	4	5	5	N
26693	ANDERSON CREEK RD	ANDERSON CREEK	3	Steel	Stringer/Girder	1	29	30	1983	4	5	5	N
20160	EAST FORK ROAD	S.FK.SALMON RIVER	3	Steel	Stringer/Girder	3	70	184	1940	4	5	6	N
14565	SH 52	SNAKE RIVER;PAYETTE BR.	3	Steel Continuous	Stringer/Girder	3	239	689	1953	4	6	5	N
28130	LITTLE ROCK ROAD	NOBLE DRAIN	3	Steel	Stringer/Girder	1	22	26	1955	4	6	5	N
14805	SH 55	UPRR;N.FK.PAYETTE RIVER	3	Concrete	Arch-Deck	8	189	411	1933	5	3	5	N
28235	RIVER ROAD	VINSON WASH	3	Steel	Stringer/Girder	1	34	36	1930	5	3	5	N
26725	STC 7787;PLYMOUTH	BOISE RIVER & CANAL	3	Steel	Truss-Thru	3	128	388	1922	5	4	4	N
27610	SMA 7733;KIMBALL A	INDIAN CREEK	3	Concrete	Slab	2	24	39	1933	5	4	5	N
27745	14TH AVE N.	INDIAN CREEK	3	Steel	Stringer/Girder	1	32	34	1947	5	5	4	N
28635	SMITH FERRY DRIVE	N.FK.PAYETTE RIVER	3	Concrete	Stringer/Girder	6	40	240	1959	5	5	4	N
26445	OLD HWY 95	LITTLE SALMON RIVER	3	Steel	Truss-Thru	1	60	63	1923	5	6	4	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
28830	SAGE CREEK ROAD	SAGE CREEK	3	Steel	Stringer/Girder	1	29	31	1965	5	6	4	N
28795	STC 3007;UNITY RD	WEISER RIVER	3	Steel	Truss-Thru	2	150	303	1910	6	4	4	N
16590	I 84 WB ON RAMP	BOISE RIVER;RAMP DA BR	3	Prestressed Concrete	Stringer/Girder	4	98	401	1980	6	4	6	N
21760	NHS 7773;10TH AVE	CITY ST;UPRR;CALDWELL OP	3	Concrete Continuous	Tee Beam	12	53	621	1956	6	4	6	N
27010	S3792;UPPR PLEASNT	DEER FLAT CANAL	3	Wood or Timber	Stringer/Girder	2	17	37	1950	6	4	6	N
27620	GALLOWAY ROAD	I 84;GALLOWAY ROAD GS	3	Prestressed Concrete	Stringer/Girder	3	52	219	1962	6	4	6	N
28225	SAGE ROAD	SUCCOR CREEK	3	Steel	Truss-Thru	1	90	94	1930	6	4	7	N
27415	STC 3851;HEXON RD	BOISE RIVER	3	Concrete	Stringer/Girder	11	30	331	1954	6	5	2	N
28805	STC 8217;COVE ROAD	WEISER RIVER	3	Steel	Truss-Thru	3	80	249	1917	6	5	3	N
26533	MIDDLE FORK ROAD	M.FK.WEISER RIVER	3	Wood or Timber	Stringer/Girder	1	31	32	1957	6	6	3	N
28355	BIG FLAT ROAD	BIG WILLOW CREEK	3	Prestressed Concrete	Tee Beam	1	29	31	1970	6	6	3	N
26490	JACKSON CREEK RD	WEISER RIVER	3	Steel	Stringer/Girder	1	81	85	1988	6	6	4	N
27990	STC 3809;MIDDLE FK	QUEENS RIVER NO. 2	3	Steel	Truss-Thru	1	60	63	1962	6	6	4	N
28855	LOWER CRANE ROAD	CRANE CREEK	3	Steel	Stringer/Girder	3	20	61	1955	6	7	4	N
33615	ELK SUMMIT RD	SOUTH FORK SALMON RIVER	3	Steel	Truss-Thru	1	250	310	1934	6	7	4	N
26565	WILDHORSE ROAD	WILDHORSE RIVER	3	Steel	Truss-Thru	1	46	48	1908	7	4	4	N
28298	SALMON CREEK RD	REYNOLDS CREEK	3	Steel	Stringer/Girder	1	26	32	1960	7	5	4	N
26394	OR 86 (HWY 012)	SNAKE RIVER (OXBOW)	3	Steel	Stringer/Girder	9	60	482	1961	7	6	4	N
26452	AIRPORT RD	WEISER RIVER	3	Steel	Stringer/Girder	1	58	61	1982	7	6	4	N
26530	OLD HORNET ROAD	HORNET CREEK	3	Steel	Stringer/Girder	1	39	40	1949	7	6	4	N
28470	BLUFF ROAD	BIG WILLOW CREEK	3	Prestressed Concrete	Tee Beam	2	35	71	1962	7	6	4	N
26617	CEMETARY RD	BEAR CREEK	3	Steel	Stringer/Girder	1	31	36	1983	8	6	4	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
20068	STC 3988;ROSEBERRY	WILLOW CREEK	3	Steel	Culvert	4	6	30	1996	N	N	N	4
28570	NISULA ROAD	MUD CREEK	3	Steel	Culvert	4	7	41	1986	N	N	N	4
17780	SH 75	YANKEE FK OF SALMON RIVR	4	Concrete Continuous	Tee Beam	5	45	200	1934	4	4	5	N
24310	2050 EAST ROAD	LITTLE WOOD RIVER	4	Steel	Stringer/Girder	1	33	34	1930	4	4	5	N
13650	US 30	UPRR;BICKEL OVERPASS	4	Concrete Continuous	Tee Beam	3	58	158	1936	4	5	5	N
24355	1700 SOUTH ROAD	BIG WOOD RIVER	4	Steel	Stringer/Girder	1	31	32	1930	4	5	5	N
24300	1550 EAST ROAD	DRY CREEK	4	Steel	Stringer/Girder	3	21	62	1930	4	6	3	N
24690	200 EAST ROAD	T.F.NORTHSIDE MAIN CNL	4	Concrete	Tee Beam	1	35	37	1970	4	6	6	N
24603	600 NORTH ROAD	'R' CANAL	4	Steel	Stringer/Girder	1	30	31	1950	5	4	3	N
24820	CO. RD.;OLD US 93	'U' CANAL	4	Concrete	Tee Beam	4	37	152	1934	5	4	4	N
24468	S 100 E	CLOVER CREEK	4	Steel Continuous	Stringer/Girder	2	20	41	1985	5	4	5	N
25030	550 EAST ROAD	MILNER GOODING CANAL	4	Steel Continuous	Stringer/Girder	4	21	79	1940	5	4	5	N
25105	STC2784;MILLARD RD	MILNER GOODING CANAL	4	Steel Continuous	Stringer/Girder	4	19	78	1955	5	4	6	N
23780	KILPATRICK BR. RD.	SILVER CREEK	4	Steel	Stringer/Girder	2	32	65	1978	5	5	2	N
24955	JIM BROWN BRIDGE R	LITTLE WOOD RIVER	4	Steel	Stringer/Girder	1	51	53	1965	5	5	3	N
13660	US 30	DRY CREEK	4	Concrete	Arch-Deck	1	55	60	1934	5	5	4	N
24540	50 NORTH ROAD	'L' CANAL	4	Steel	Stringer/Girder	1	26	27	1950	5	5	4	N
24545	RIDGEWAY ROAD	'C' CANAL	4	Prestressed Concrete	Channel Beam	1	31	32	1963	5	5	4	N
19525	STC2781;1300 S. RD	THORN CREEK	4	Steel	Stringer/Girder	3	24	72	1955	5	6	4	N
24965	30 SOUTH ROAD	MILNER GOODING CANAL	4	Steel	Stringer/Girder	4	20	79	1977	5	6	4	N
24945	1220 NORTH ROAD	EAST MAIN CANAL	4	Concrete	Stringer/Girder	2	16	34	1959	6	4	4	N
25085	1150 EAST ROAD	EAST MAIN CANAL	4	Steel Continuous	Stringer/Girder	2	17	37	1977	6	4	4	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
24910	NORTH BIRCH STREET	LITTLE WOOD RIVER	4	Steel	Truss-Thru	1	60	63	1913	6	4	6	N
23785	LTL WOOD RES. ROAD	MULDOON CREEK	4	Steel	Stringer/Girder	1	34	41	1954	6	5	3	N
24970	850 EAST ROAD	EAST MAIN CANAL	4	Steel Continuous	Stringer/Girder	2	20	40	1965	6	5	3	N
14400	SH 46	MINEAR CREEK	4	Concrete	Stringer/Girder	1	29	30	1955	6	5	4	N
25025	850 WEST ROAD	MILNER GOODING CANAL	4	Steel	Stringer/Girder	1	34	36	1950	6	5	4	N
24655	STC2768;2400 E. RD	MILNER GOODING CANAL	4	Prestressed Concrete	Tee Beam	1	74	76	1970	6	6	2	N
16545	I 84 EBL	DRAIN	4	Concrete	Frame	1	28	30	1968	6	6	4	N
19475	STC2744;1900 E. RD	'C' CANAL	4	Prestressed Concrete	Tee Beam	1	25	26	1965	6	6	4	N
24605	990 SOUTH ROAD	'C' CANAL	4	Prestressed Concrete	Tee Beam	1	25	26	1962	6	6	4	N
24705	1100 SOUTH ROAD	'C' CANAL	4	Prestressed Concrete	Tee Beam	1	27	28	1975	6	6	4	N
24740	HUNT ROAD	T.F.NORTHSIDE MAIN CNL	4	Prestressed Concrete	Tee Beam	1	66	67	1960	6	6	4	N
24960	250 WEST ROAD	N. GOODING CANAL	4	Steel	Stringer/Girder	1	27	28	1975	6	6	4	N
24905	NORTH APPLE STREET	LITTLE WOOD RIVER	4	Steel	Girder-Floorbeam	1	44	45	1920	7	4	5	N
23865	SWAMP ROAD	CAMAS CREEK	4	Wood or Timber	Stringer/Girder	3	13	41	1965	7	5	4	N
23800	200 SOUTH ROAD	CAMAS CREEK	4	Steel	Truss-Thru	2	30	117	1920	8	4	4	N
23860	SWAMP ROAD	CAMAS CREEK	4	Wood or Timber	Stringer/Girder	3	15	47	1965	8	6	3	N
23795	200 SOUTH ROAD	CAMAS CREEK	4	Wood or Timber	Stringer/Girder	3	14	43	1950	8	6	4	N
19365	STC2714;3700 NORTH	ROCK CREEK	4	Steel	Culvert	1	21	21	1973	N	N	N	4
21380	STC7232;BLUE LAKES	ROCK CREEK	4	Steel	Culvert	3	10	39	1959	N	N	N	4
22175	STC7151;BENTON ST	PORTNEUF RIVER	5	Steel	Stringer/Girder	1	45	47	1969	3	5	6	N
17540	US 91	BLACKFOOT CANAL	5	Concrete	Tee Beam	1	42	43	1951	4	4	5	N
11440	I 15 SBL	I15B;UPRR;S.BLACKFOOT IC	5	Prestressed Concrete	Stringer/Girder	5	78	392	1961	4	4	6	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
11445	I 15 NBL	I15B;UPRR;S.BLACKFOOT IC	5	Prestressed Concrete	Stringer/Girder	5	78	392	1961	4	4	6	N
22025	E. SUBLETTE ROAD	PORTNEUF MARSH VAL.CNL	5	Prestressed Concrete	Tee Beam	1	26	27	1968	4	4	6	N
16695	US 89	BEAR LAKE CANAL	5	Prestressed Concrete	Stringer/Girder	3	53	163	1973	4	5	6	N
16700	US 89	BEAR RIVER	5	Prestressed Concrete	Stringer/Girder	2	63	129	1973	4	6	6	N
11175	I 15 NBL	MAIN STREET GS	5	Concrete	Stringer/Girder	3	41	124	1962	5	4	4	N
11180	I 15 SBL	MAIN STREET GS	5	Concrete	Stringer/Girder	3	41	124	1962	5	4	4	N
17520	US 91	GIBSON LATERAL CANAL	5	Steel	Stringer/Girder	1	27	28	1923	5	4	4	N
22160	ROSS FORK RD	I 15 NB-SB;FORT HALL IC	5	Prestressed Concrete	Stringer/Girder	3	49	212	1960	5	4	5	N
23345	PARKINSON ROAD	CUB RIVER	5	Concrete	Stringer/Girder	2	24	51	1926	5	4	5	N
11280	I 15 SBL	I 86 WB RAMP	5	Prestressed Concrete	Stringer/Girder	3	98	216	1962	5	4	6	N
23060	SCOTT RD; W 100 S	ABERDEEN SPRINGFIELD CNL	5	Prestressed Concrete	Tee Beam	2	45	92	1964	5	5	2	N
23360	WESTON-FAIRVIEW RD	BEAR RIVER;E.WESTON BR.	5	Concrete	Tee Beam	5	34	175	1956	5	5	3	N
23235	8 MILE ROAD	BEAR RIVER	5	Steel	Stringer/Girder	1	96	100	1972	6	3	5	N
11185	I 15 NBL	I 15B;W.INKOM IC	5	Concrete	Stringer/Girder	3	37	114	1962	6	4	5	N
11285	I 15 SBL	I 86 EB RAMP	5	Prestressed Concrete	Stringer/Girder	3	98	229	1962	6	4	6	N
12090	I 15B ;US 91	BLACKFOOT RIVER	5	Concrete Continuous	Tee Beam	2	37	106	1936	6	4	6	N
23305	DIAMOND CREED ROAD	BLACKFOOT RIVER	5	Prestressed Concrete	Slab	1	42	43	1971	6	5	2	N
23120	SMA 7611;W. BRIDGE	SNAKE RIVER	5	Steel	Truss-Thru	2	210	483	1936	6	5	3	N
21975	STC 1757;MAIN ST	PORTNEUF RIVER	5	Concrete	Stringer/Girder	1	42	43	1962	6	6	2	N
10920	I 86B ROCKLAND IC	I 86 EB-WB;ROCKLAND IC	5	Prestressed Concrete	Multiple Box Beam	5	58	245	1959	7	4	5	N
23100	FERRY BUTTE RD	I 15;FERRY BUTTE ROAD GS	5	Prestressed Concrete	Stringer/Girder	5	49	282	1959	7	4	6	N
23105	WILLIE RD	I 15;WILLIE ROAD GS	5	Prestressed Concrete	Stringer/Girder	3	49	212	1959	7	4	6	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
23645	AIRPORT ROAD	I 86 EB-WB;AIRPORT IC	5	Prestressed Concrete	Stringer/Girder	5	71	312	1968	7	4	7	N
23186	CHESTERFIELD RES R	CHESTERFIELD CANAL	5	Steel	Stringer/Girder	1	44	46	2005	7	7	4	N
32240	US 20 FRONTAGE RD	N. BRANCH FALL RIVER CNL	6	Concrete	Frame	1	24	24	1932	4	4	4	N
33037	S 1000 W	TRAIL CREEK	6	Concrete	Tee Beam	1	24	25	1995	4	4	4	N
21035	STC 6774;TETON HWY	S.FK.TETON RIVER	6	Prestressed Concrete	Multiple Box Beam	3	48	150	1977	4	4	5	N
32245	US 20 FRONTAGE RD	FALL RIVER OVERFLOW	6	Concrete	Frame	1	24	24	1932	4	4	5	N
32505	N 4400 E (SHELTON)	BURGESS CANAL	6	Prestressed Concrete	Multiple Box Beam	1	44	45	1969	4	4	5	N
31585	DIVERSION ROAD	CAMAS CREEK	6	Steel	Stringer/Girder	1	25	27	1953	4	6	5	N
31565	OLD HWY 91	UPRR;N.SPENCER RR OP	6	Steel	Truss-Thru	1	161	296	1936	4	6	6	N
31740	SQUAW CREEK RD	SQUAW CREEK	6	Prestressed Concrete	Tee Beam	1	23	24	1960	5	4	4	N
21585	SMA 7406;17TH ST	SAND CREEK	6	Prestressed Concrete	Stringer/Girder	3	30	70	1957	5	4	5	N
31290	N 45TH E	SAND CREEK	6	Prestressed Concrete	Multiple Box Beam	3	30	71	1957	5	4	5	N
31730	SQUAW CREEK ROAD	SQUAW CREEK	6	Prestressed Concrete	Tee Beam	1	23	24	1960	5	4	5	N
31840	FUN FARM ROAD	HENRYS FK SNAKE RIVER	6	Steel	Truss-Thru	1	152	157	1925	5	4	6	N
36100	E 421 N	LEWISVILLE CANAL	6	Concrete	Tee Beam	1	35	39	1960	5	4	6	N
21075	1300 N	HENRYS FK.SNAKE R;FRITZ	6	Prestressed Concrete	Tee Beam	3	64	197	1967	5	5	4	N
31700	OLD CHILLI ROAD	THOUSAND SPRINGS CREEK	6	Concrete	Tee Beam	1	25	26	1926	5	5	4	N
32690	VIOLA LANE	LEMHI RIVER(BAGLEY BR)	6	Steel	Multiple Box Beam	1	72	74	1991	5	5	4	N
11985	I 15 NBL	HUMPHREY ROAD IC	6	Concrete	Stringer/Girder	3	37	114	1966	6	4	5	N
13955	SH 33	SPRING CREEK	6	Concrete	Channel Beam	1	41	43	1975	6	4	6	N
32475	2350 NORTH	CAMAS CREEK	6	Prestressed Concrete	Tee Beam	1	29	30	1972	6	4	6	N
31650	MULE SHOE MINE RD	SALMON RIVER;SE.CLAYTON	6	Steel	Truss-Thru	1	150	152	1930	6	5	4	N

BRIDGE_ID	FACILITY	FEATINT	DISTRICT	MATERIAL	DESIGN	SPANS	MAXSPANLEN	LENGTH	YEARBUILT	DKRATING	SUPRATING	SUBRATING	CULVRATING
32270	E 700 N RD	BUTTE MARKET LAKE CANAL	6	Wood or Timber	Stringer/Girder	2	29	60	1962	6	6	3	N
31170	W 33RD S	GREAT WESTERN CANAL	6	Prestressed Concrete	Stringer/Girder	1	23	25	1930	6	6	4	N
31595	VADNAIS LANE	CAMAS CREEK	6	Steel	Stringer/Girder	1	28	32	1981	6	6	4	N
31605	STC 6760;RED ROAD	CAMAS CREEK	6	Prestressed Concrete	Tee Beam	2	21	45	1953	6	6	4	N
31705	SQUAW CREEK RD	SQUAW CREEK	6	Prestressed Concrete	Tee Beam	1	23	24	1960	6	6	4	N
31855	N 4075 E	MARYSVILLE CANAL	6	Prestressed Concrete	Tee Beam	1	23	25	1976	6	6	4	N
32755	N. ST. CHARLES	LEMHI RIVER	6	Prestressed Concrete	Tee Beam	2	39	79	1948	6	6	4	N
31407	S 25 E; S HITT RD	SAND CREEK	6	Prestressed Concrete	Stringer/Girder	1	41	43	1994	7	4	7	N
31850	N 2700 E	CROSSCUT CANAL	6	Prestressed Concrete	Tee Beam	1	33	34	1937	7	6	4	N
31052	COMMISSARY ROAD	RAINEY CREEK	6	Prestressed Concrete	Tee Beam	1	22	24	1985	7	7	2	N
31054	RANGER STATION RD	RAINEY CREEK	6	Prestressed Concrete	Tee Beam	1	24	26	1985	7	7	2	N
32040	N 1600 E	ST ANTHONY CANAL	6	Prestressed Concrete	Tee Beam	1	25	26	1971	7	7	2	N

Appendix D. FHWA Bridge Element Condition States

The following outlines the first four bridges from the data set obtained from the FHWA website (https://www.fhwa.dot.gov/bridge/nbi/element.cfm) for Idaho.

STATE	STRUCNUM	EN	TOTALQTY	CS1	CS2	CS3	CS4	EPN
16	10000	12	87950	85547	2403	0	0	
16	10000	107	8610	8454	156	0	0	
16	10000	210	306	305	1	0	0	
16	10000	215	149	116	33	0	0	
16	10000	220	136	98	38	0	0	
16	10000	234	387	316	71	0	0	
16	10000	303	131	0	0	131	0	
16	10000	311	14	0	14	0	0	
16	10000	314	35	15	0	20	0	
16	10000	330	1237	1205	10	20	2	
16	10000	331	2474	2226	247	1	0	
16	10000	515	6063	5963	20	30	50	330
16	10000	515	56	0	0	0	56	311
16	10000	515	144008	142008	500	1500	0	107
16	10000	515	140	140	0	0	0	314
16	10000	521	72735	0	71235	0	1500	12
16	10010	12	13094	12758	261	75	0	
16	10010	109	2100	2100	0	0	0	
16	10010	215	84	76	8	0	0	
16	10010	225	49	0	0	47	2	
16	10010	234	236	79	157	0	0	
16	10010	302	369	37	329	3	0	
16	10010	310	84	82	2	0	0	
16	10010	330	1408	0	1408	0	0	
16	10010	331	40	10	30	0	0	
16	10010	510	10032	0	10017	0	15	12
16	10010	515	8800	1760	0	0	7040	330
16	10010	515	3008	0	0	0	3008	225
16	10010	521	10032	0	10017	0	15	12
16	10015	12	5328	3820	1508	0	0	
16	10015	109	720	720	0	0	0	
16	10015	215	96	82	14	0	0	
16	10015	225	16	0	0	16	0	
16	10015	234	107	106	1	0	0	

STATE	STRUCNUM	EN	TOTALQTY	CS1	CS2	CS3	CS4	EPN
16	10015	310	20	0	20	0	0	
16	10015	331	288	251	37	0	0	
16	10015	515	667	0	667	0	0	225
16	10027	12	93520	92520	1000	0	0	
16	10027	107	8494	8494	0	0	0	
16	10027	205	15	15	0	0	0	
16	10027	210	57	56	1	0	0	
16	10027	215	154	154	0	0	0	
16	10027	234	367	366	1	0	0	
16	10027	301	75	0	75	0	0	
16	10027	303	154	154	0	0	0	
16	10027	311	42	32	10	0	0	
16	10027	313	14	14	0	0	0	
16	10027	331	2514	2164	350	0	0	
16	10027	510	90206	90106	0	0	100	12
16	10027	515	14	14	0	0	0	313
16	10027	515	191228	181728	7500	2000	0	107
16	10027	515	42	42	0	0	0	311
16	10027	521	90206	90106	0	0	100	12

Appendix E. WCSD of Individual Deficient Bridge Elements

Deck Elements:

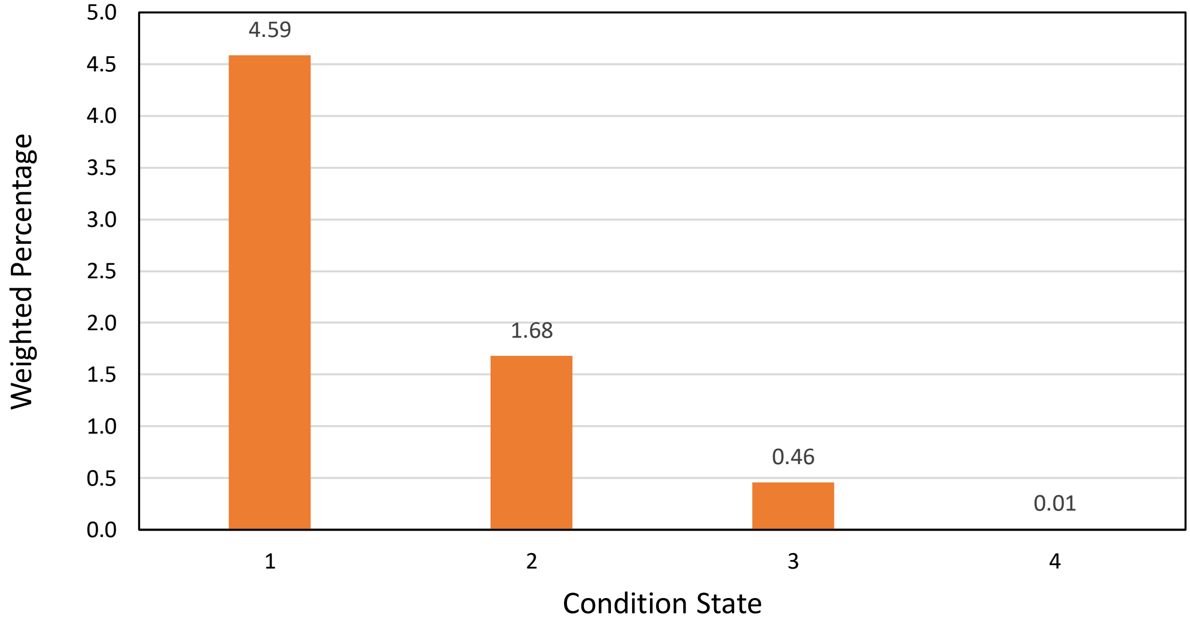


Figure E.1 Element 12, Reinforced Concrete Deck (No. of Bridges = 79).

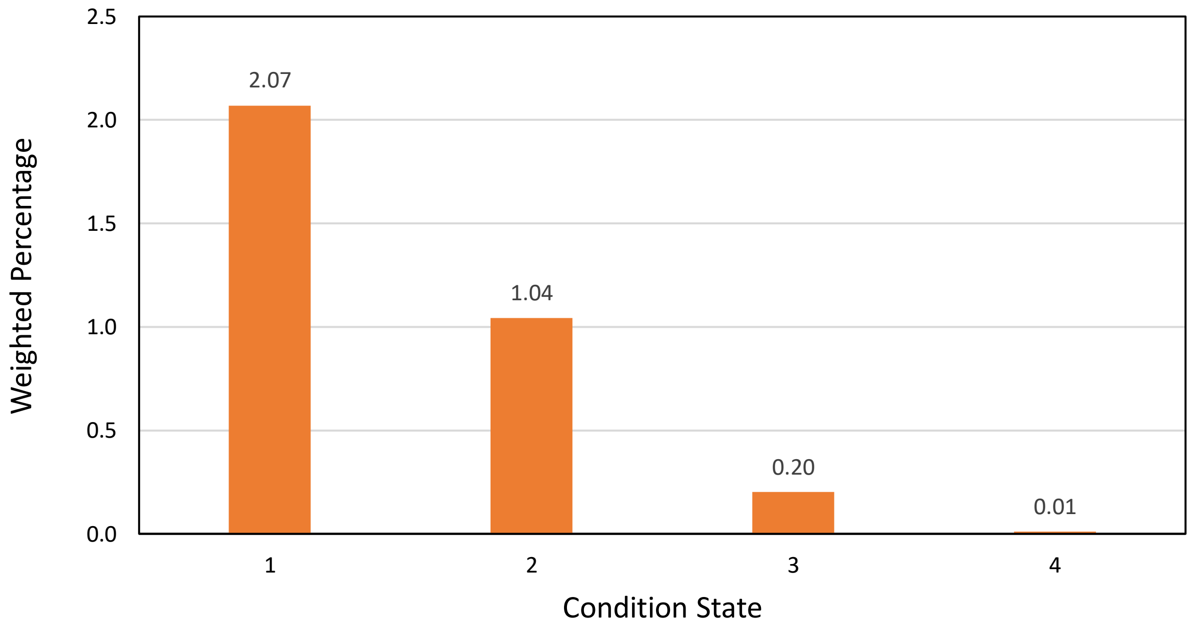


Figure E.2: Element 31, Timber Deck (No. of Bridges = 39).

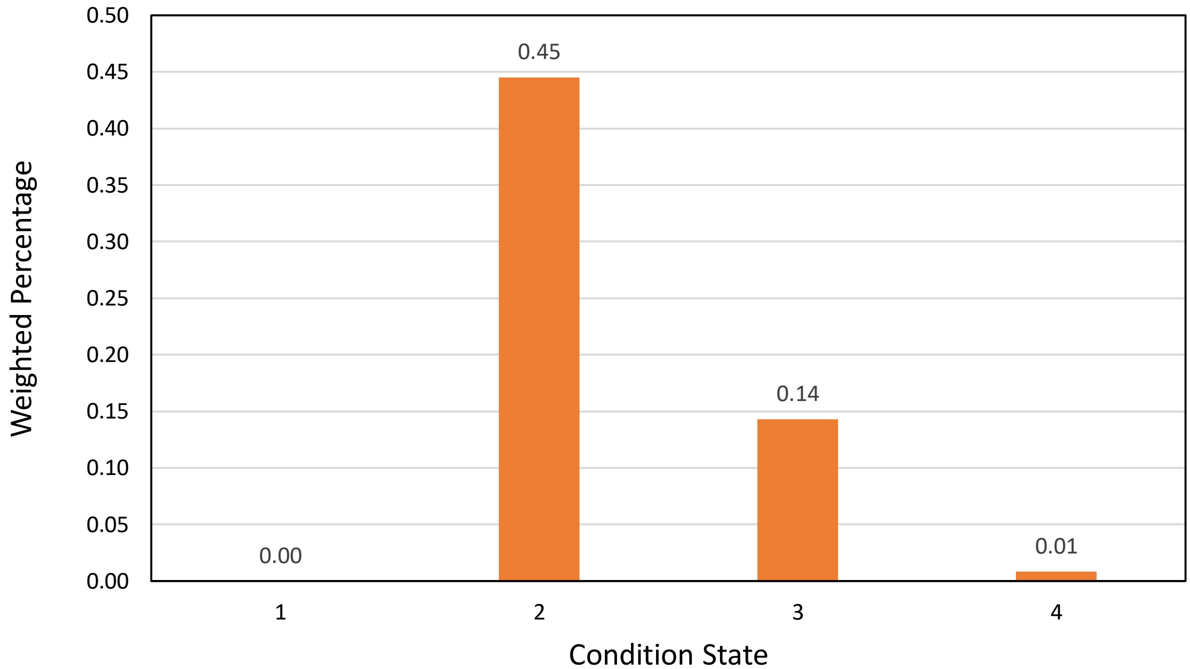


Figure E.3: Element 29, Steel Concrete Filled Deck (No. of Bridges = 7).

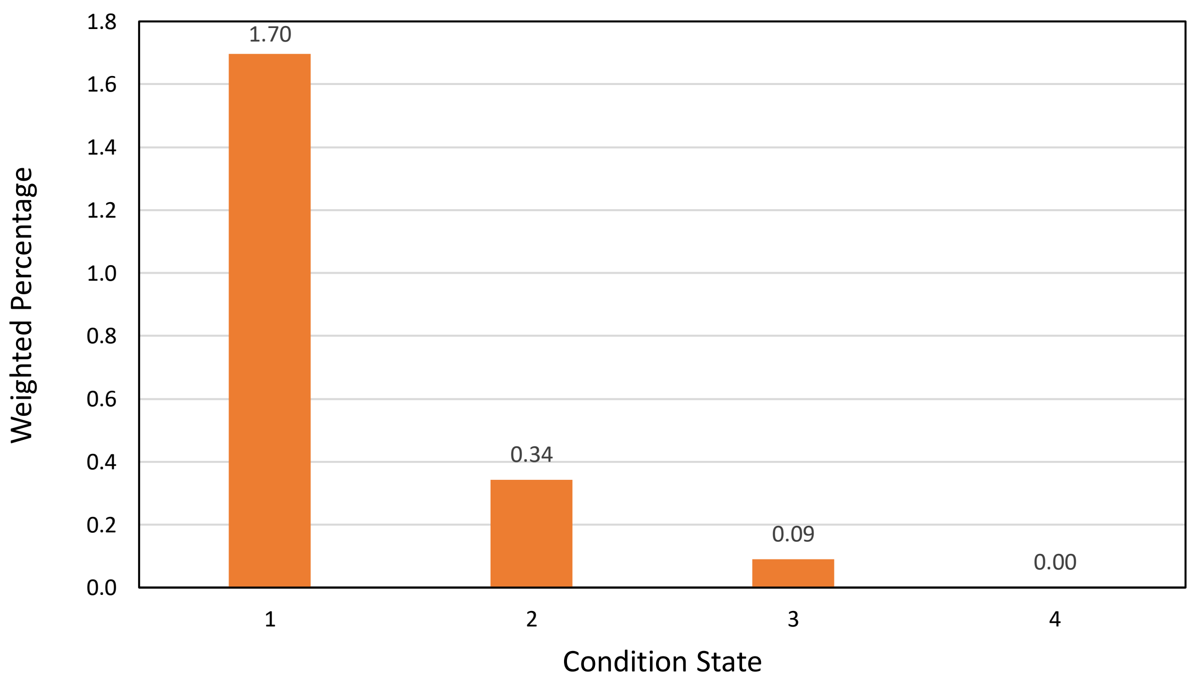


Figure E.4: Element 30, Steel C/O Deck (No. of Bridges = 25).

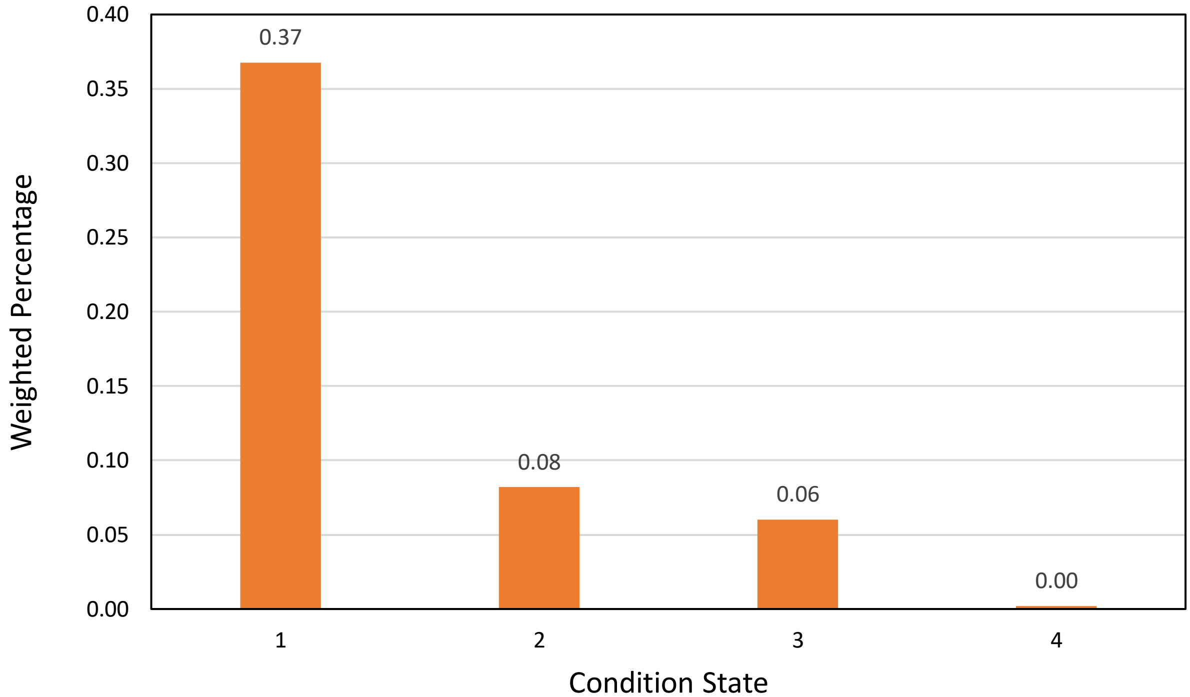


Figure E.5: Element 38, Reinforced Concrete Slab Deck (No. of Bridges = 6).

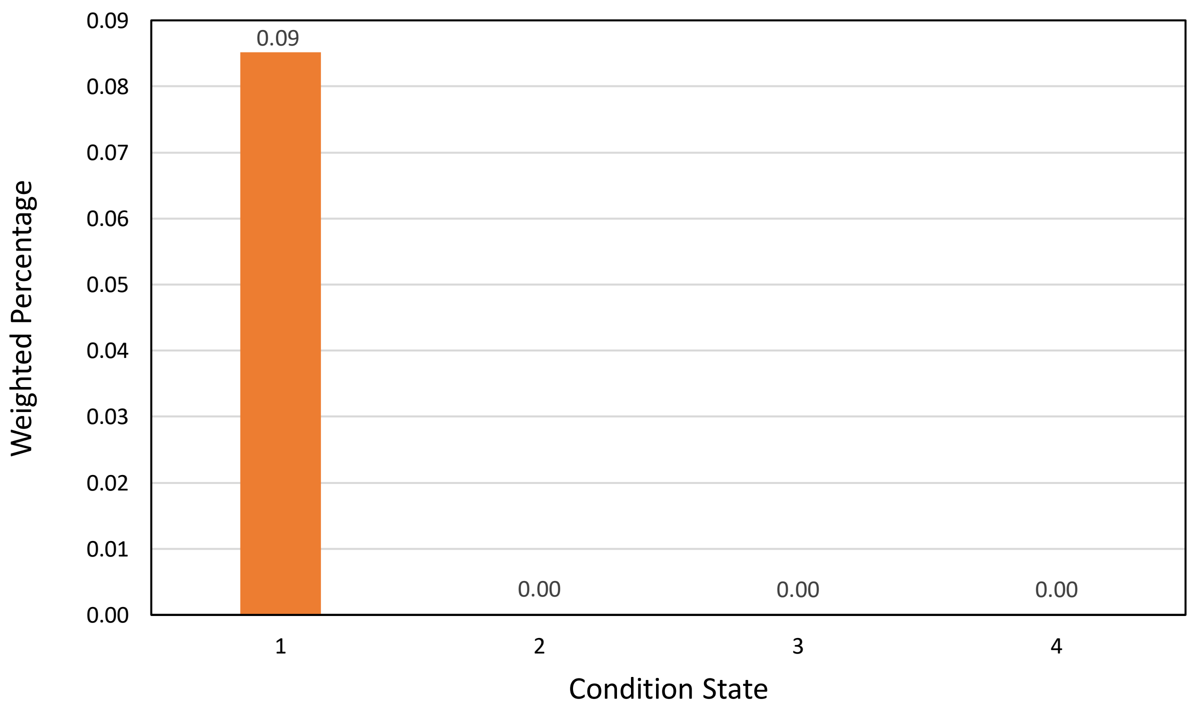


Figure E.6: Element 54, Timber Slab Deck (No. of Bridges = 1).

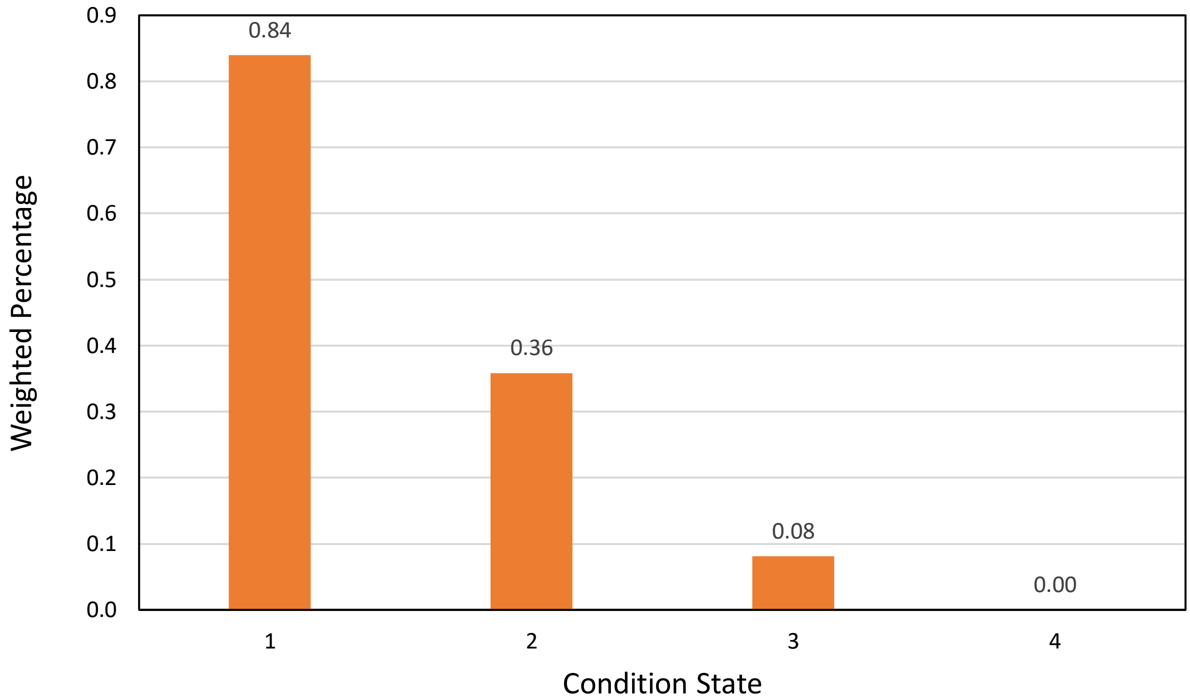


Figure E.7: Element 15, Prestressed Concrete Top Flange Deck (No. of Bridges = 15).

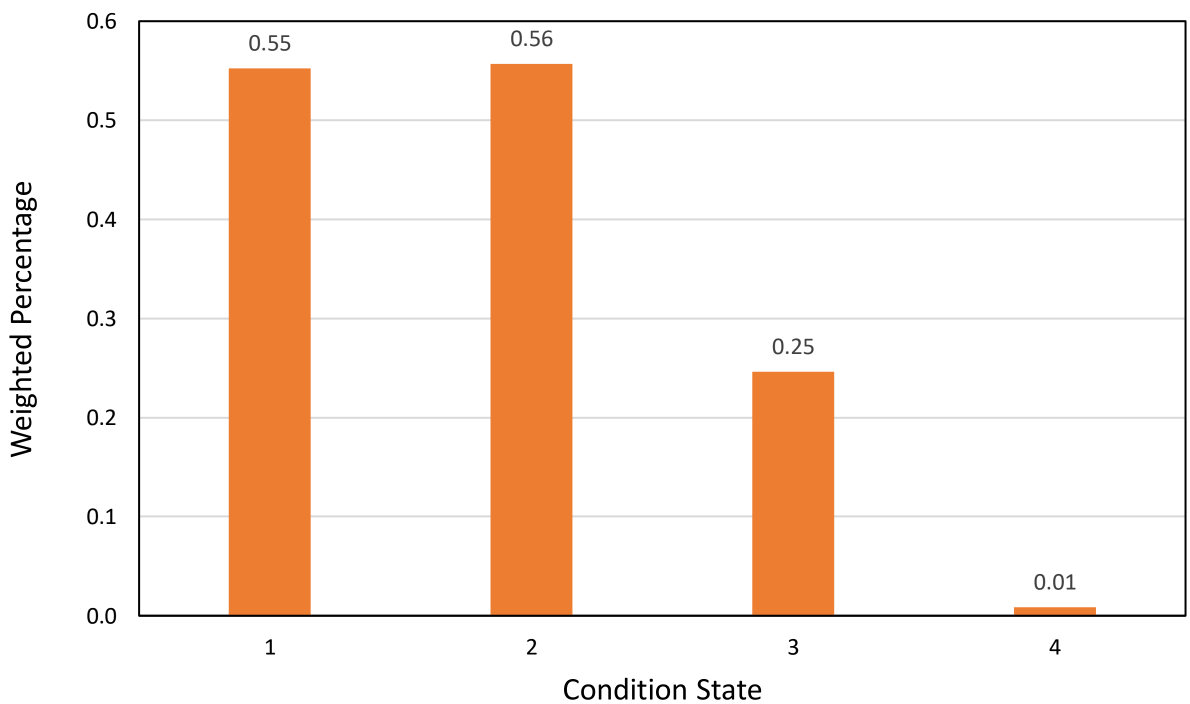


Figure E.8: Element 16, Reinforced Concrete Top Flange Deck (No. of Bridges = 16).

Superstructure Elements:

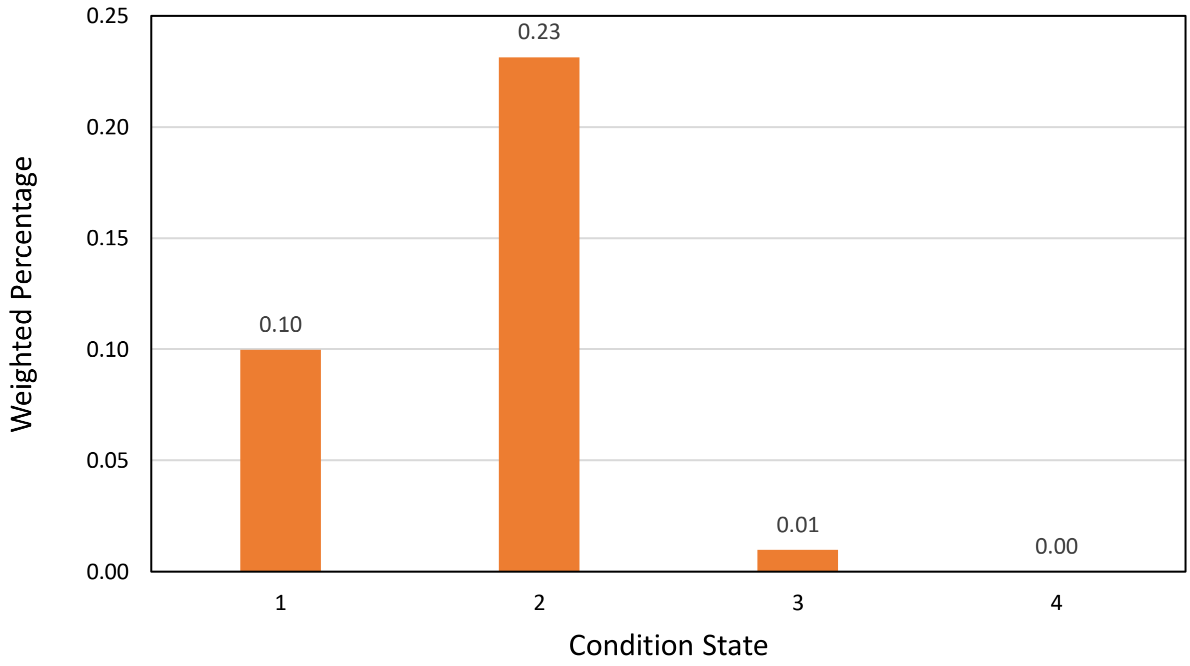


Figure E.9: Element 102, Steel Closed Web/Box Girder Superstructure (No. of Bridges = 4).

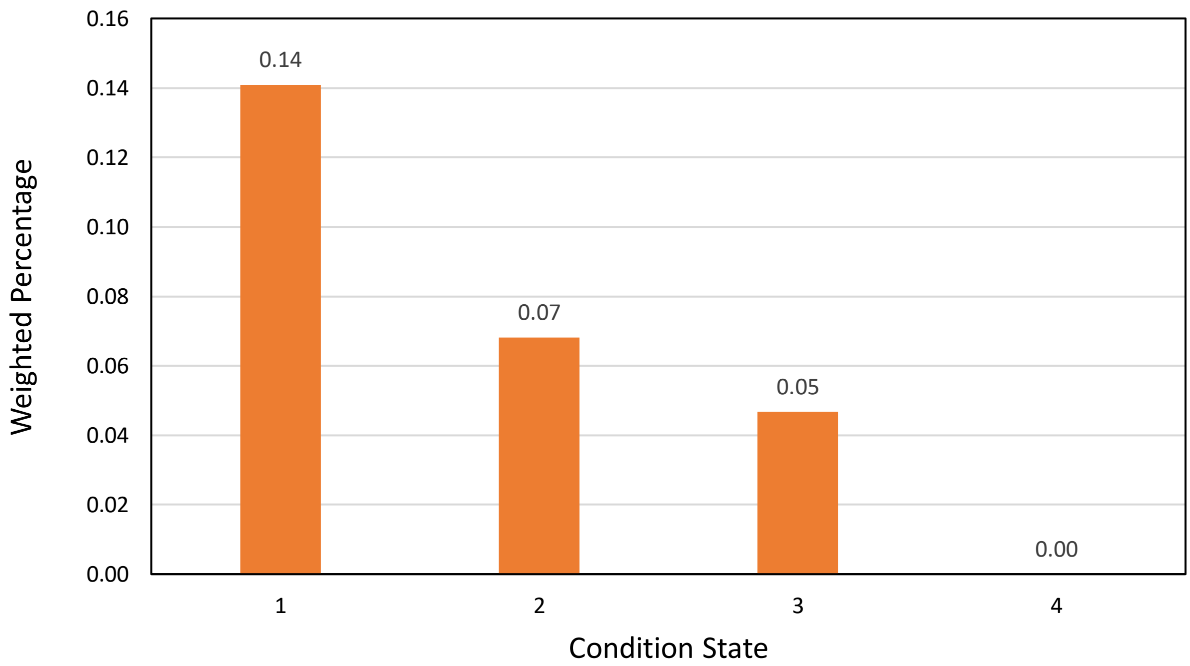


Figure E.10: Element 104, Prestressed Concrete Closed Web/Box Girder Super. (No. of Bridges = 3).

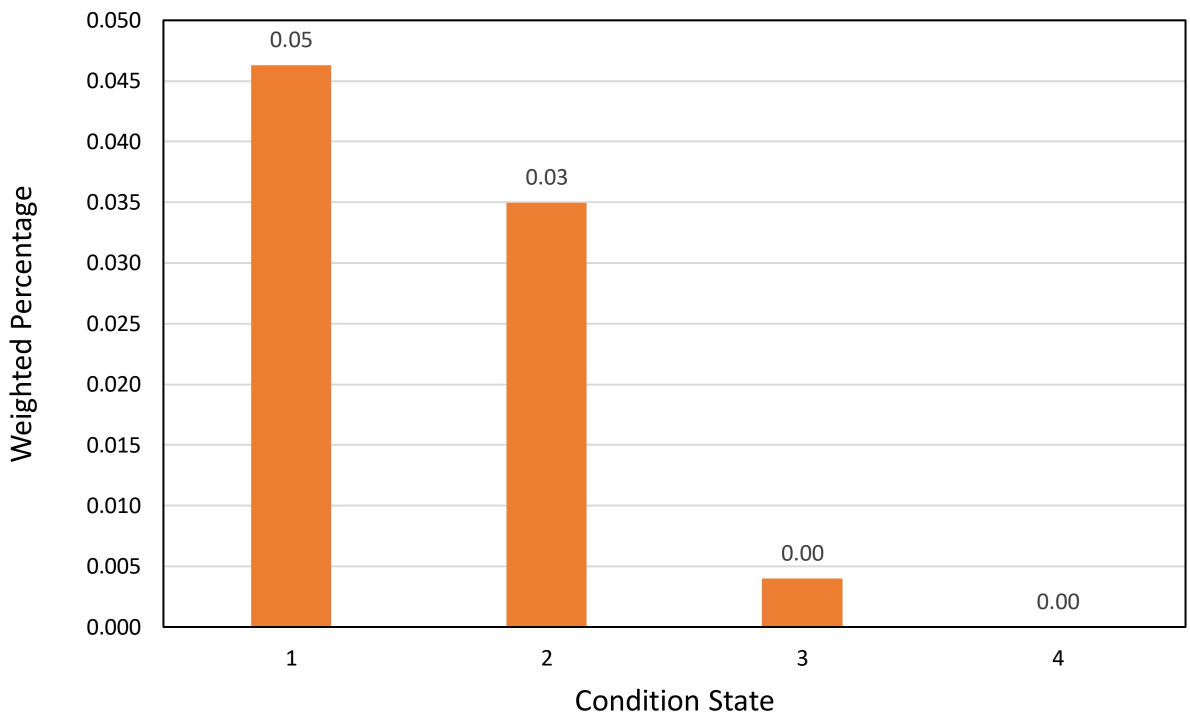


Figure E.11: Element 105, Reinforced Concrete Closed Web/Box Girder Super. (No. of Bridges = 1).

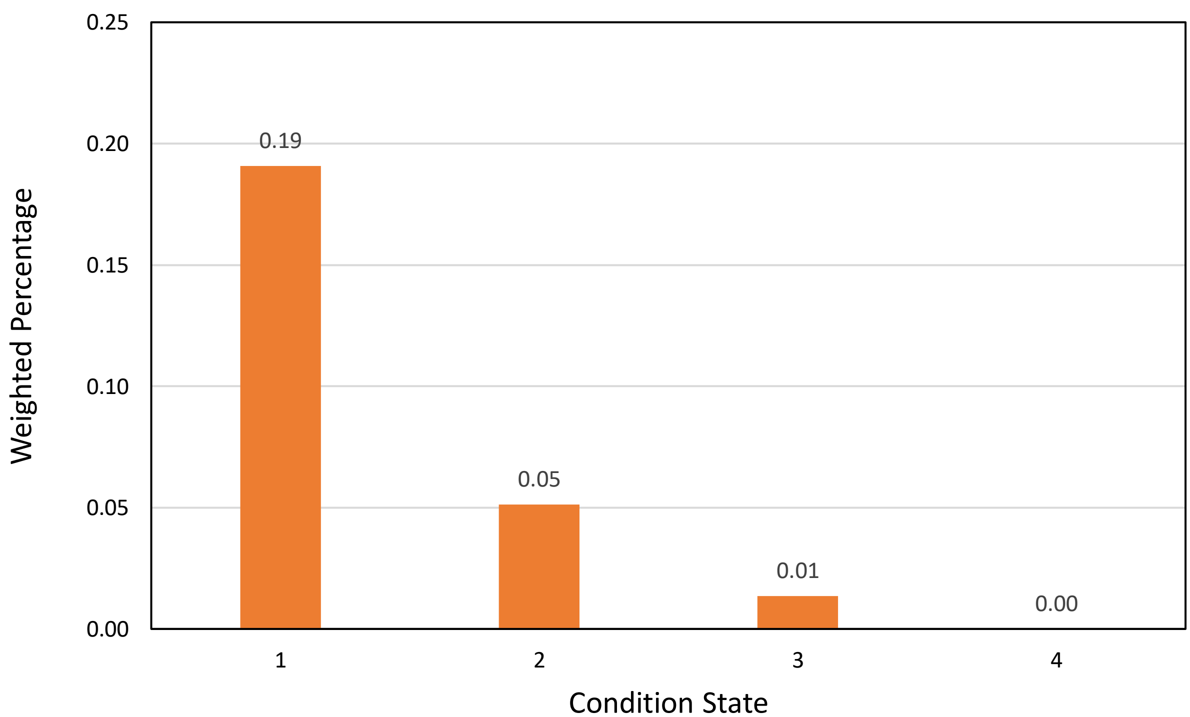


Figure E.12: Element 106, "Other Material" Closed Web/Box Girder Super. (No. of Bridges = 3).

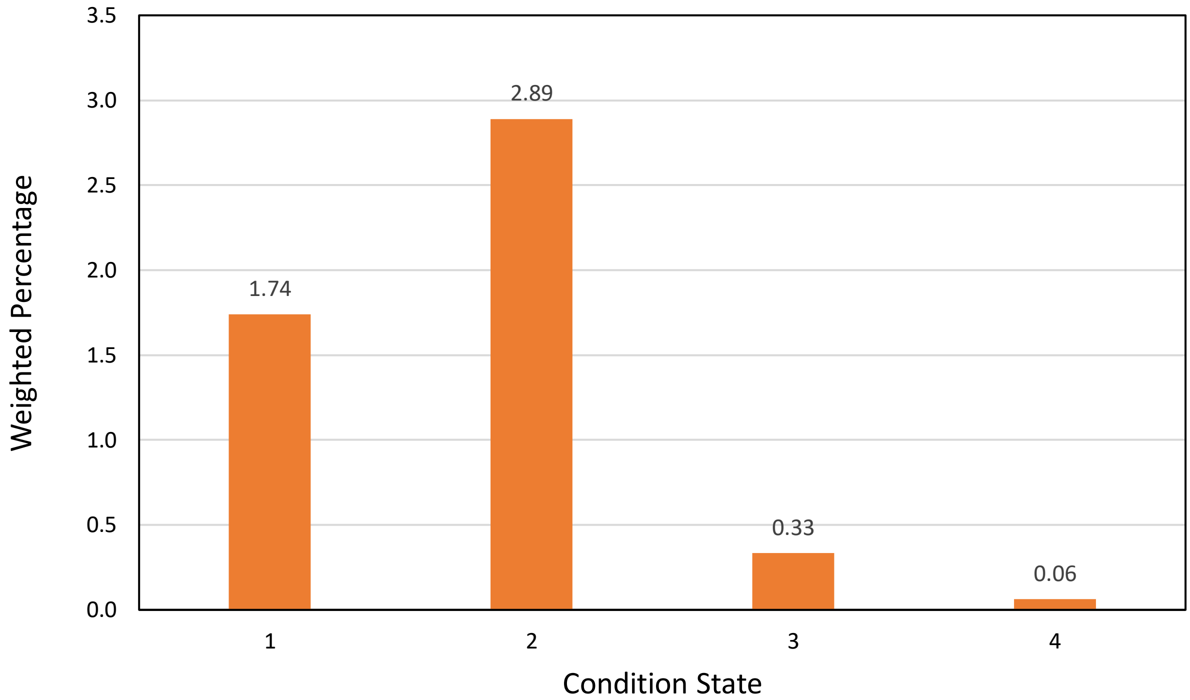


Figure E.13: Element 107, Steel Beam/Girder Superstructure (No. of Bridges = 59).

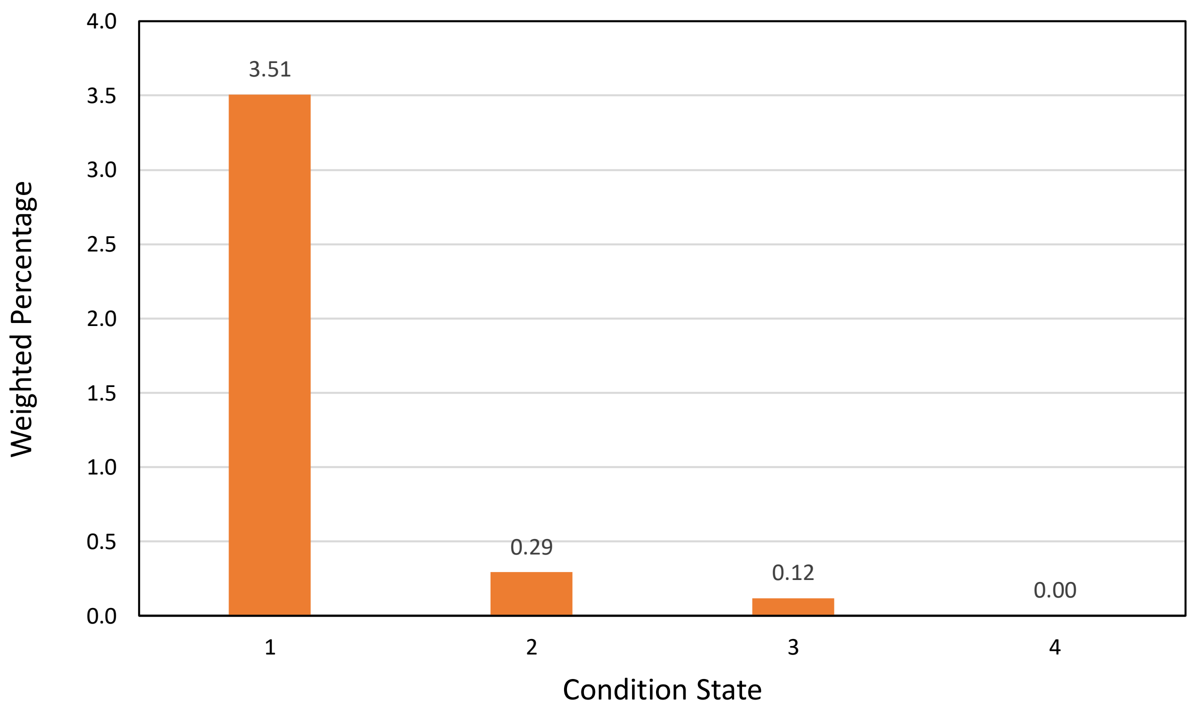


Figure E.14: Element 109, Prestressed Concrete Beam/Girder Superstructure (No. of Bridges = 46).

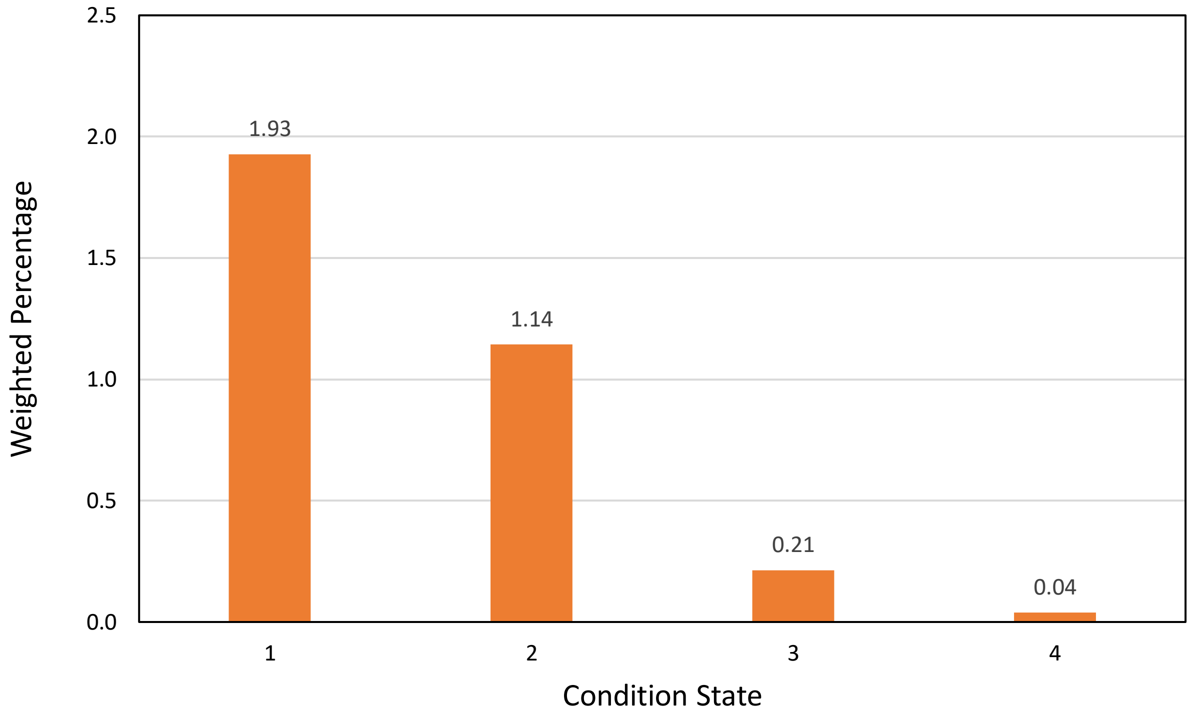


Figure E.15: Element 110, Reinforced Concrete Beam/Girder Superstructure (No. of Bridges = 39).

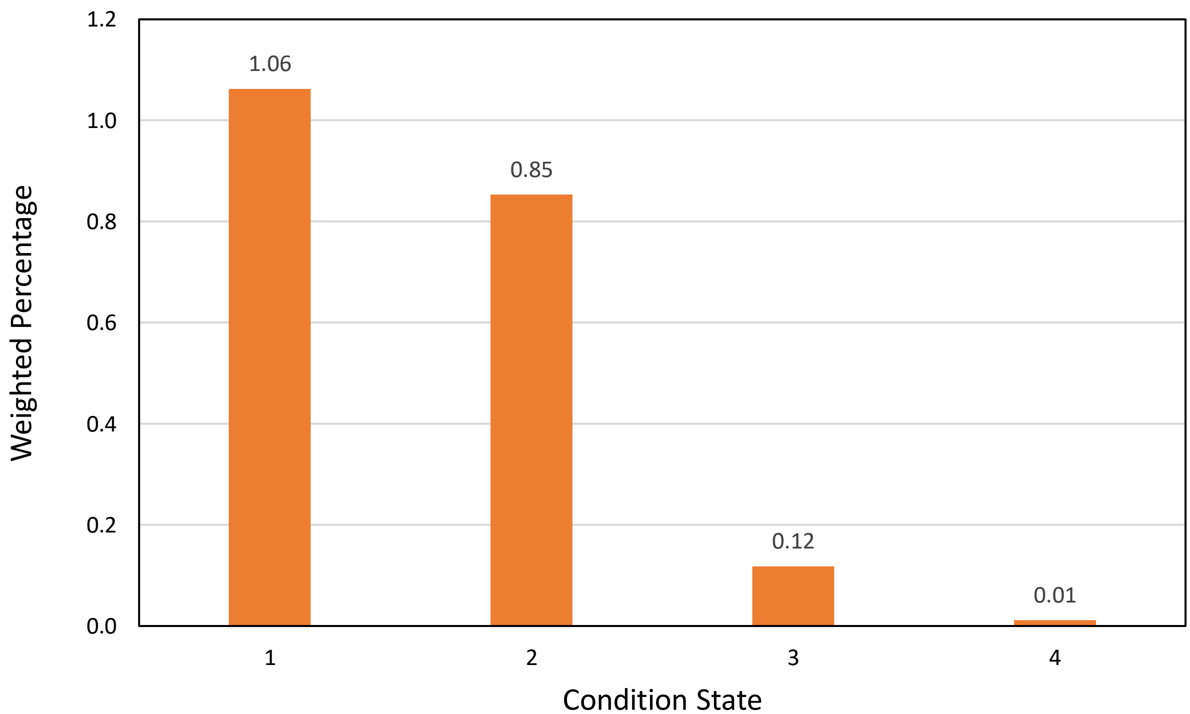


Figure E.16: Element 111, Timber Beam/Girder Superstructure (No. of Bridges = 24).

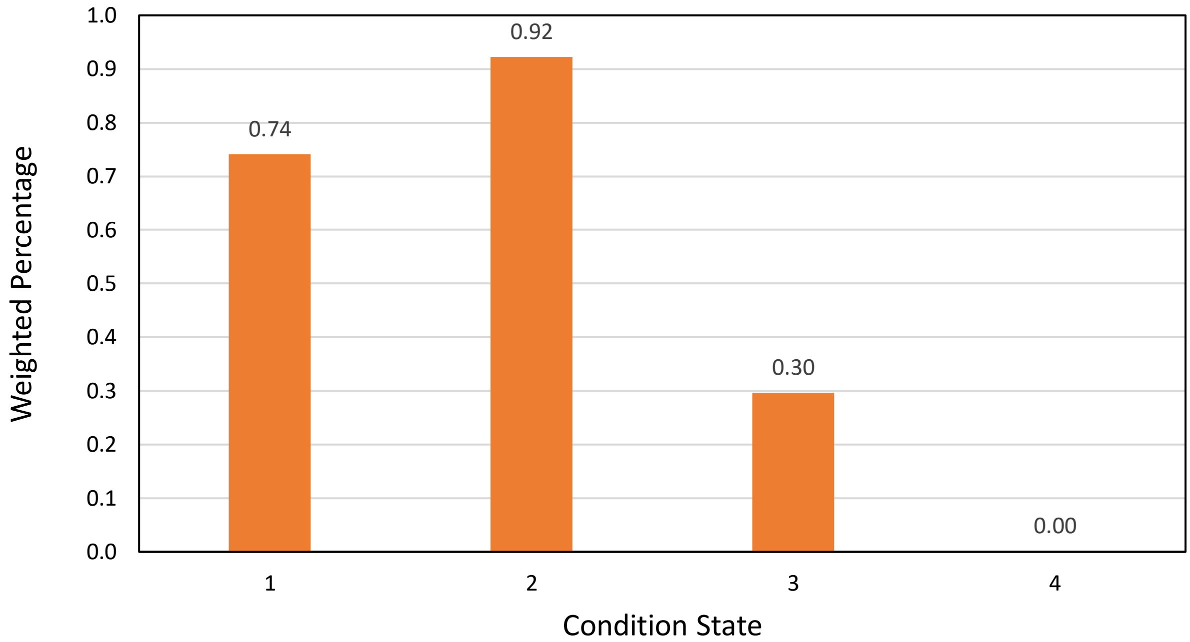


Figure E.17: Element 113, Steel Stringer Superstructure (No. of Bridges = 23).

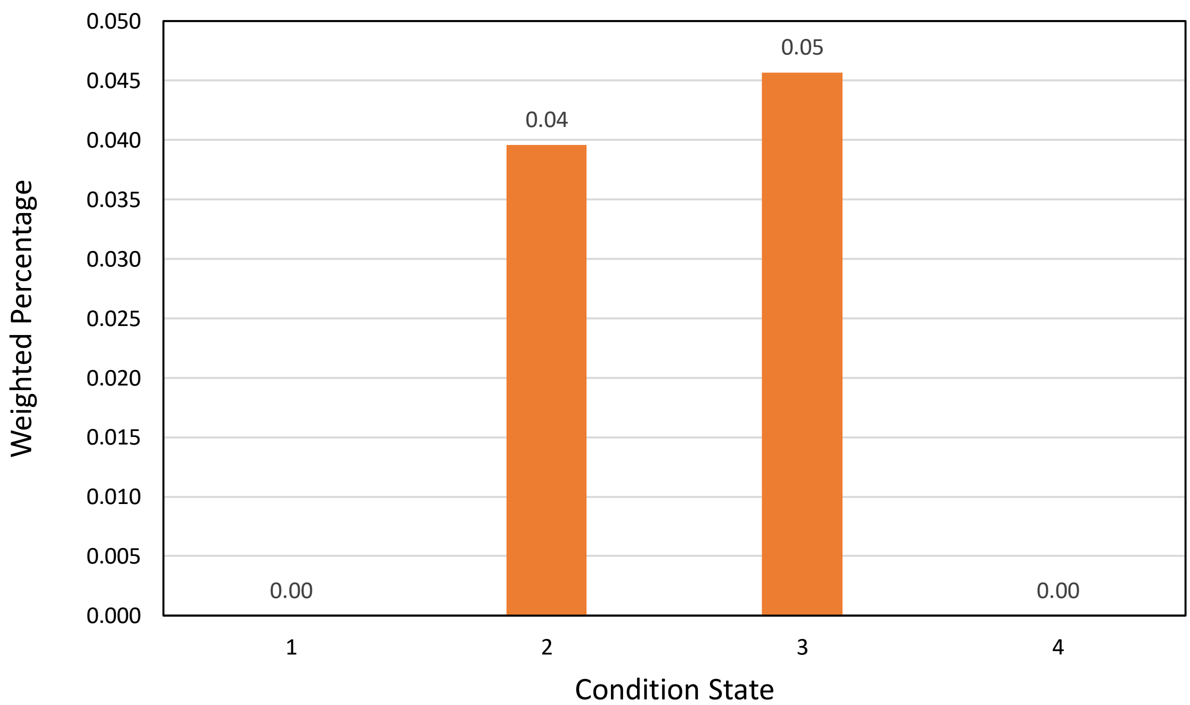


Figure E.18: Element 116, Reinforced Concrete Stringer Superstructure (No. of Bridges = 1).

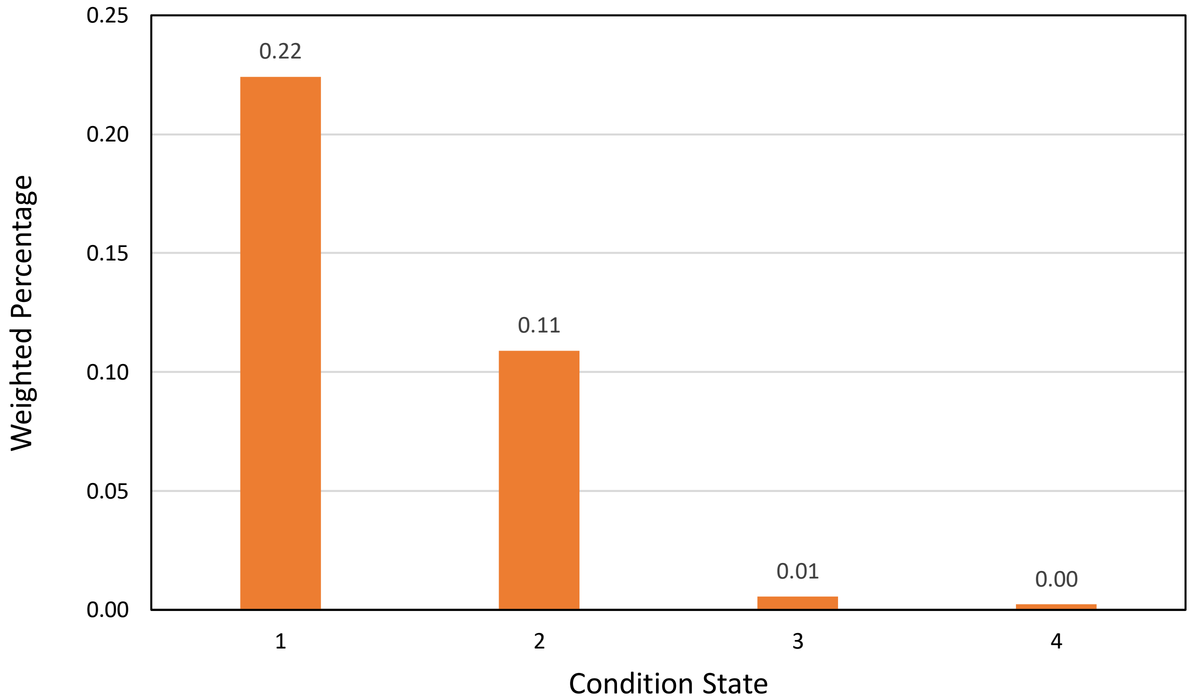


Figure E.19: Element 117, Timber Stringer Superstructure (No. of Bridges = 4).

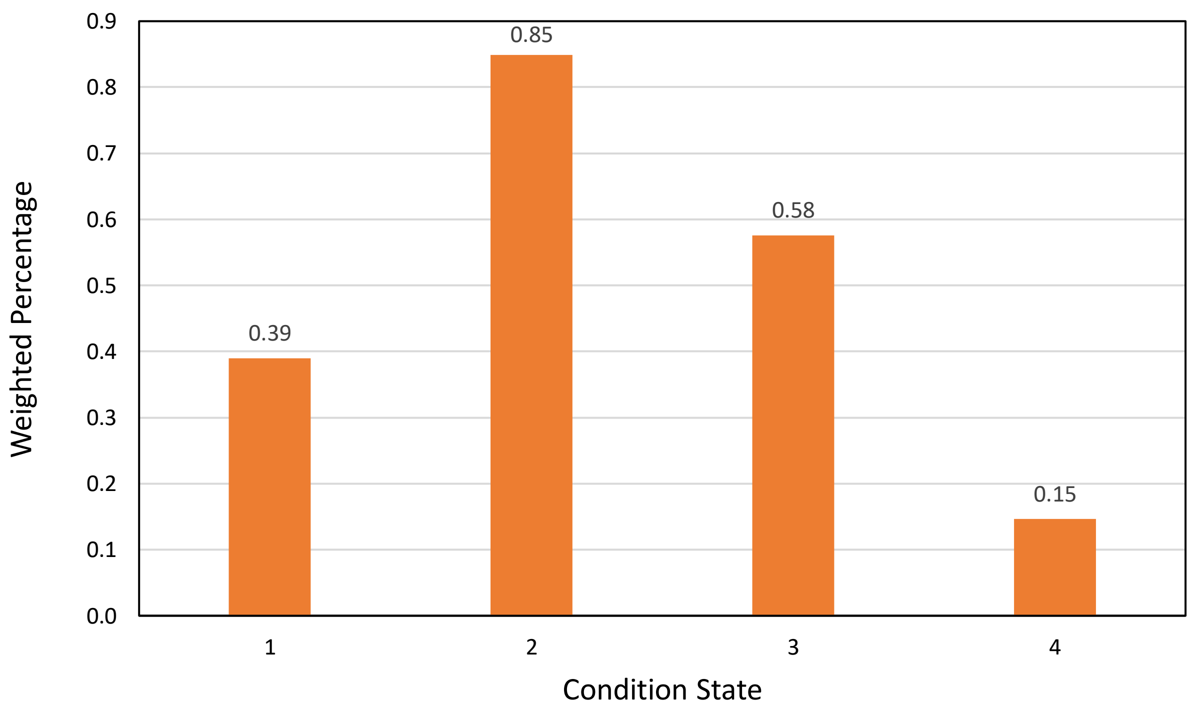


Figure E.20: Element 120, Steel Truss Superstructure (No. of Bridges = 23).

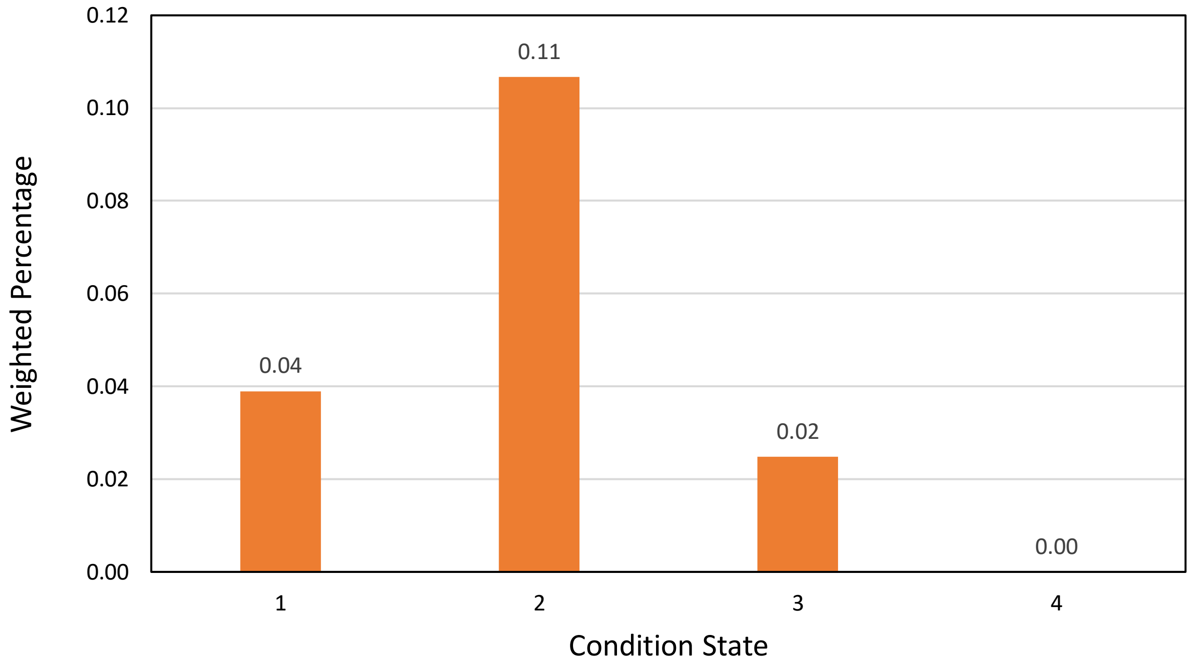


Figure E.21: Element 144, Reinforced Concrete Arch Superstructure (No. of Bridges = 2).

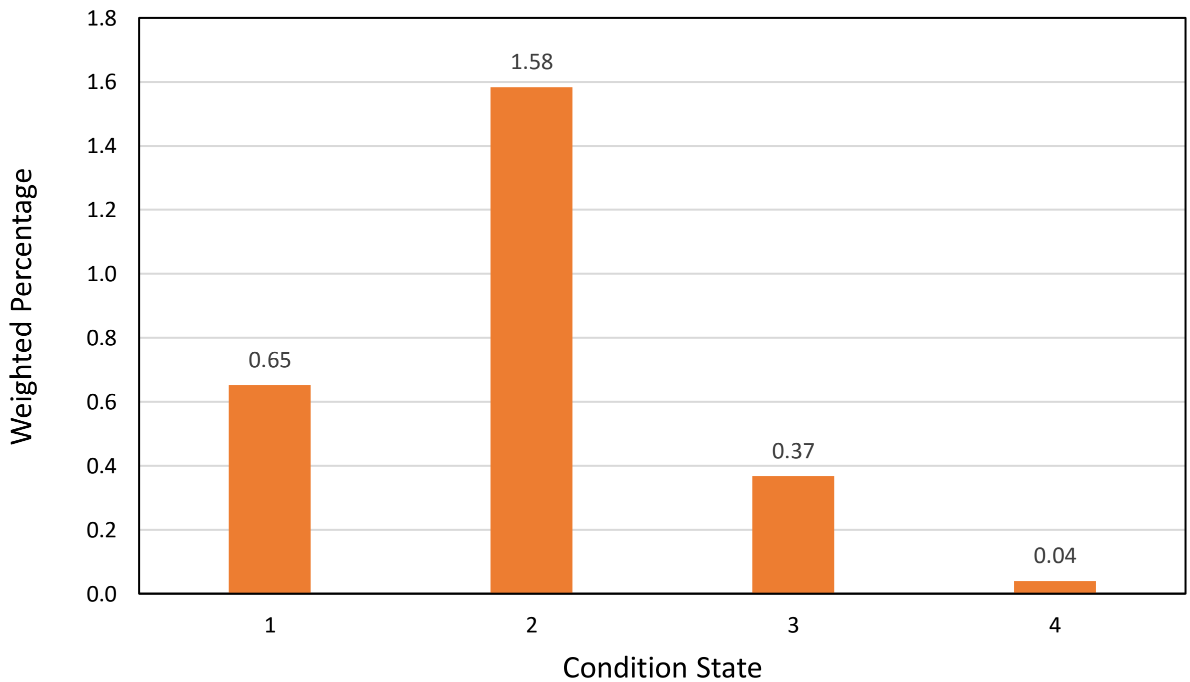


Figure E.22: Element 152, Steel Floor Beam Superstructure (No. of Bridges = 31).

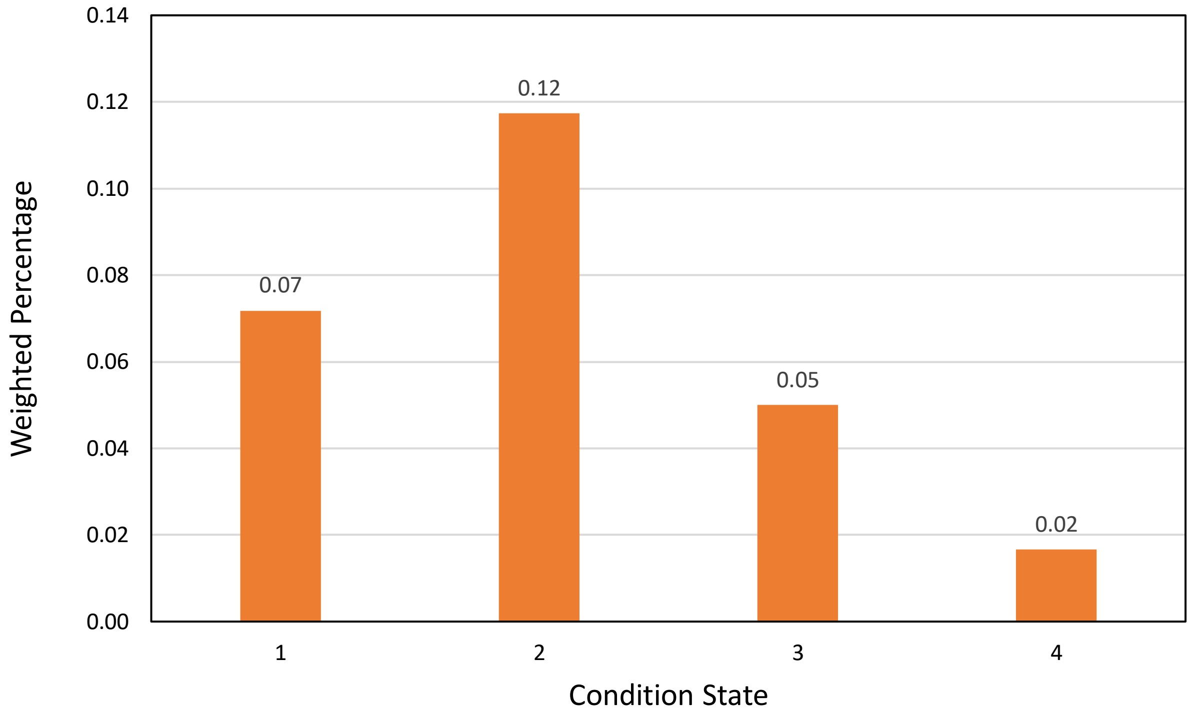


Figure E.23: Element 155, Reinforced Concrete Floor Beam Superstructure (No. of Bridges = 3).

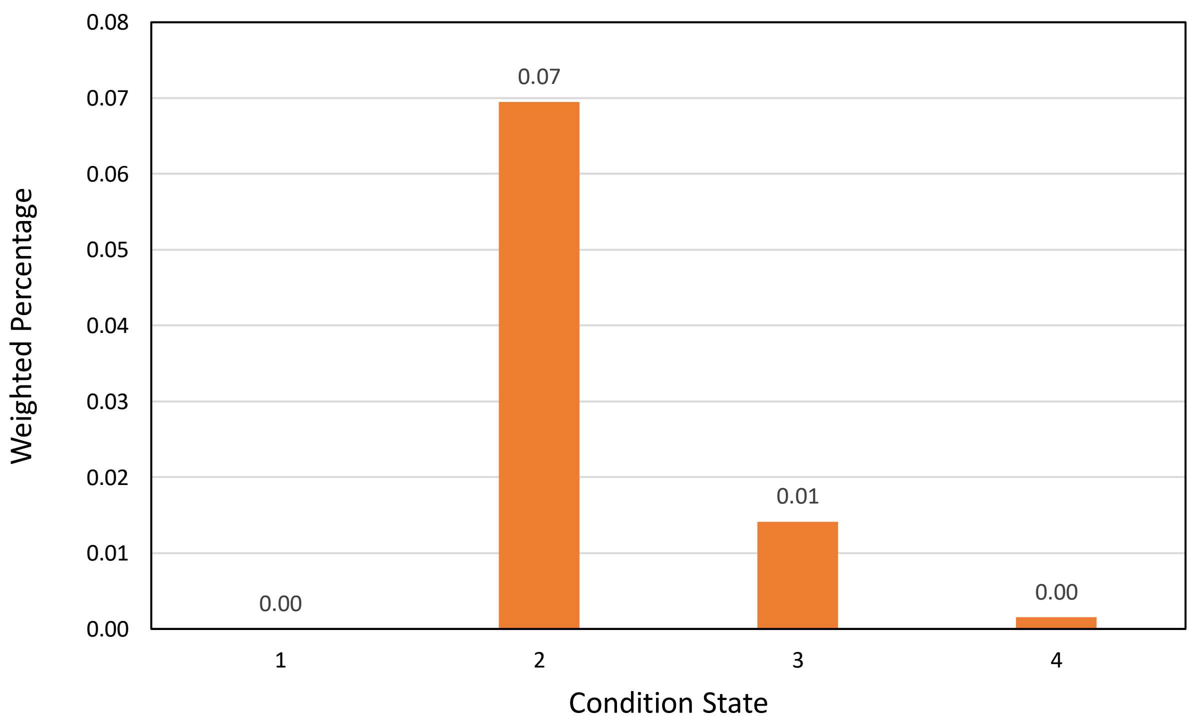


Figure E.24: Element 156, Timber Floor Beam Superstructure (No. of Bridges = 1).

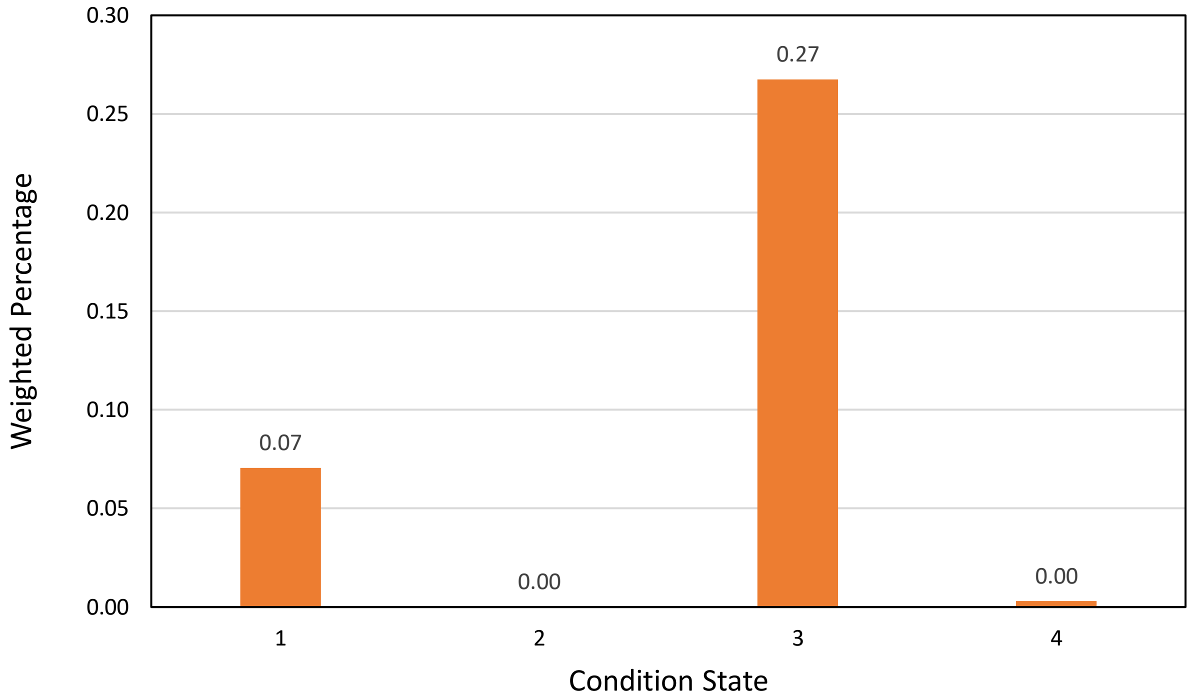


Figure E.25: Element 161, Steel Pin/Pin Hanger Assembly Superstructure (No. of Bridges = 4).

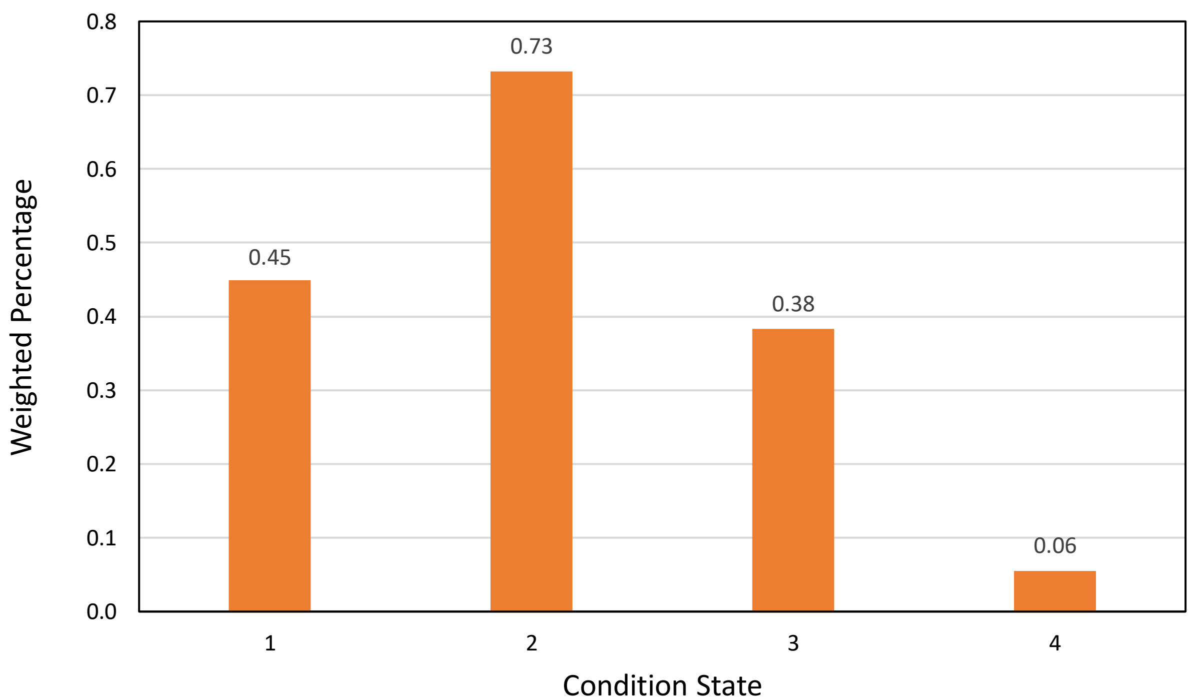


Figure E.26: Element 162, Steel Gusset Plate Superstructure (No. of Bridges = 19).

Substructure Elements:

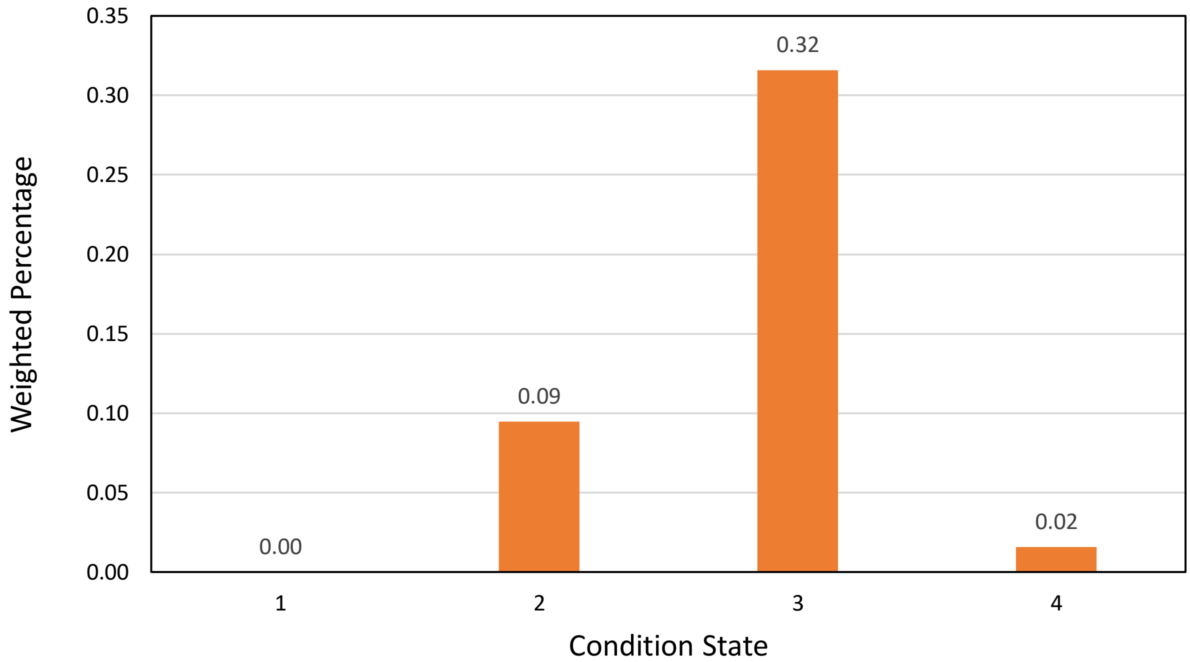


Figure E.27: Element 202, Steel Column Substructure (No. of Bridges = 5).

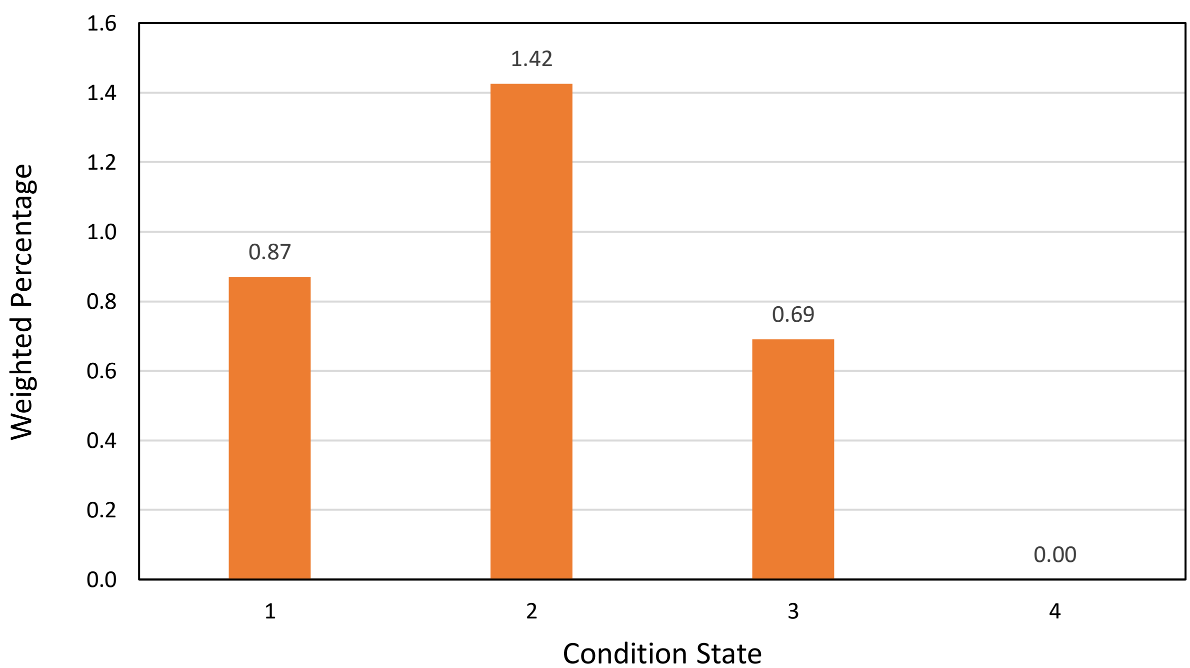


Figure E.28: Element 205, Reinforced Concrete Column Substructure (No. of Bridges = 35).

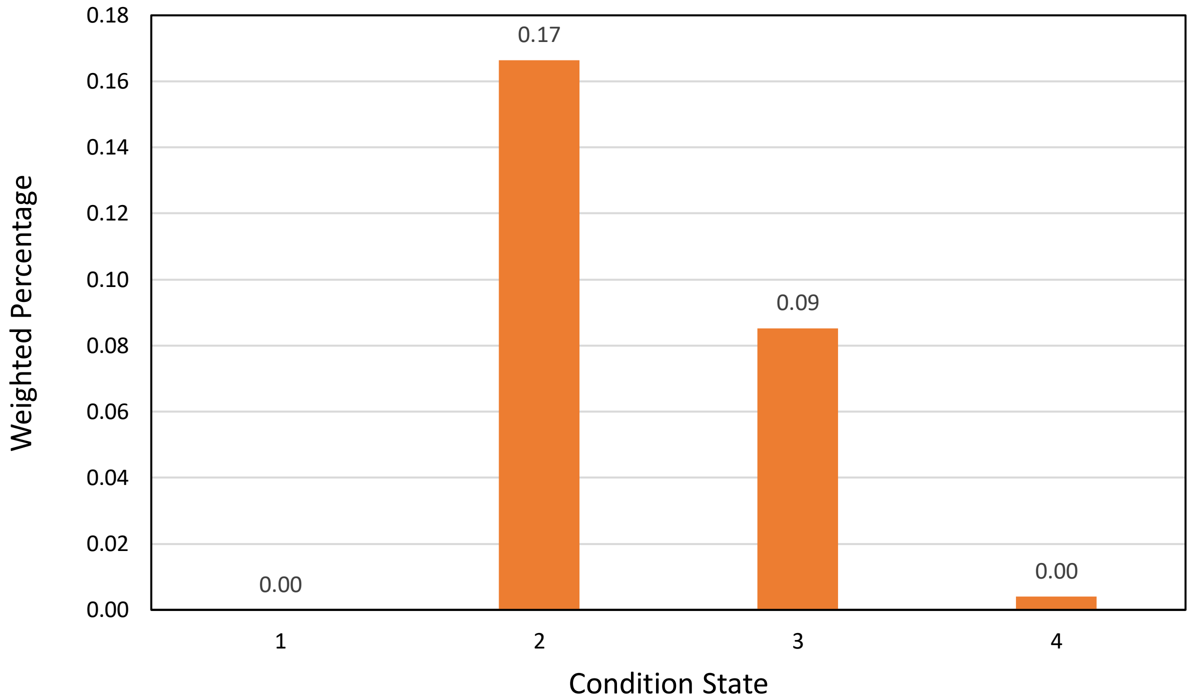


Figure E.29: Element 206, Timber Column Substructure (No. of Bridges = 3).

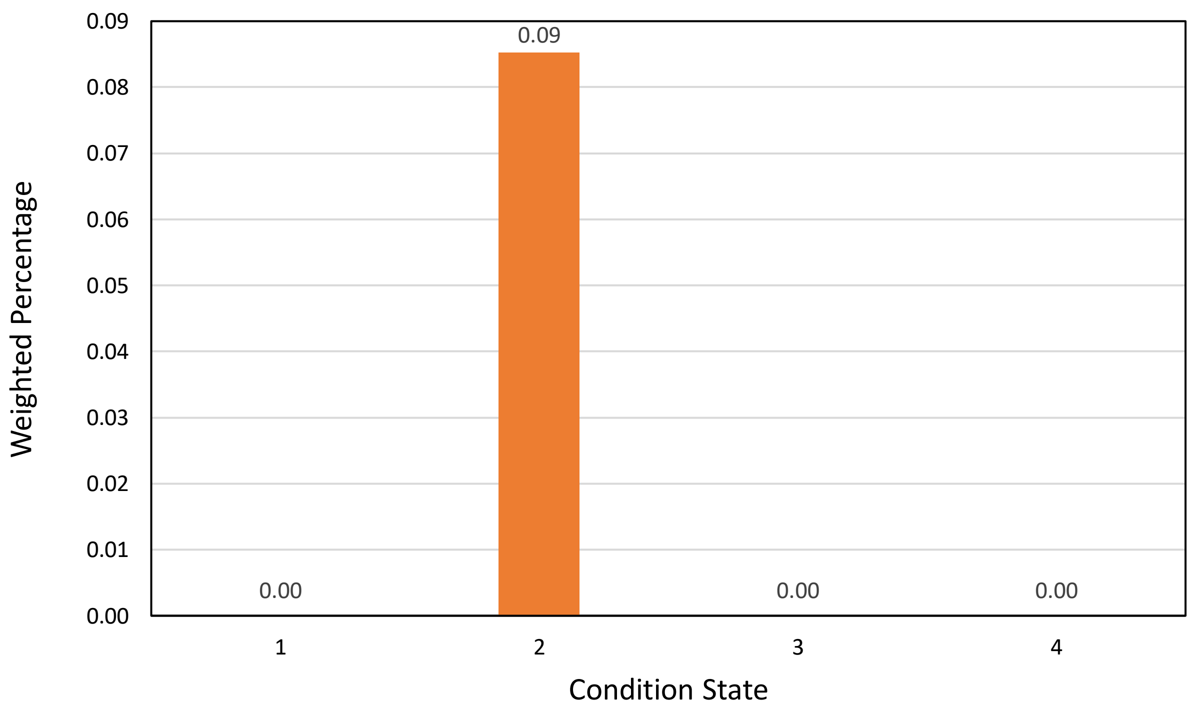


Figure E.30: Element 207, Steel Column Tower Substructure (No. of Bridges = 1).

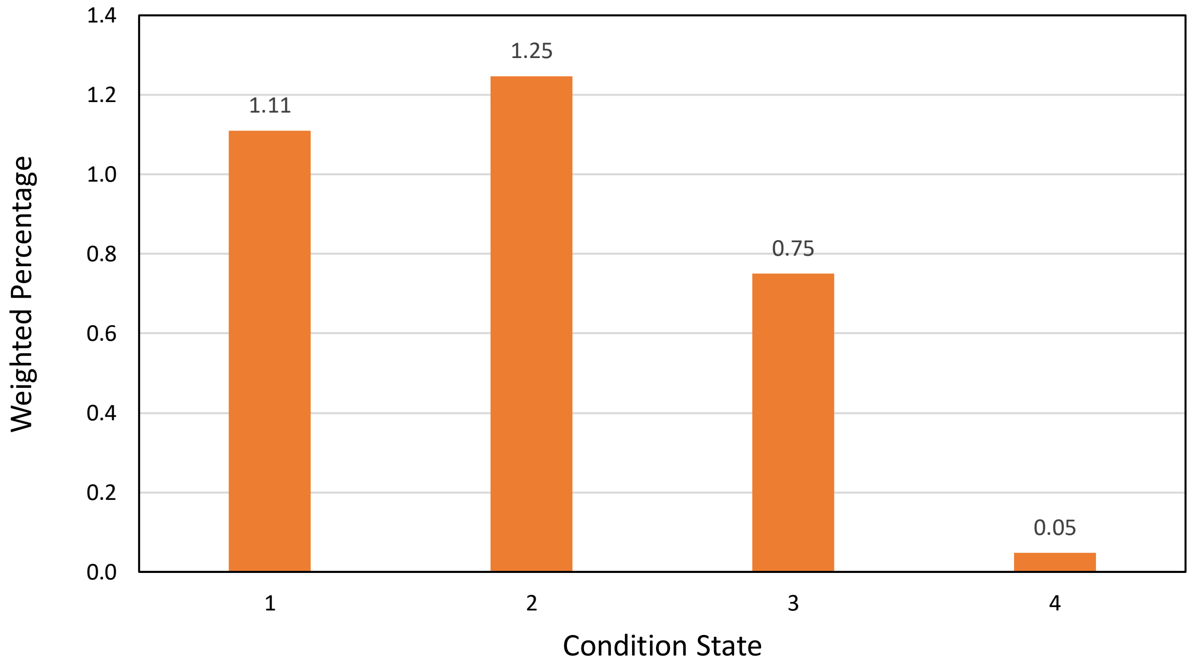


Figure E.31: Element 210, Reinforced Concrete Pier Wall Substructure (No. of Bridges = 37).

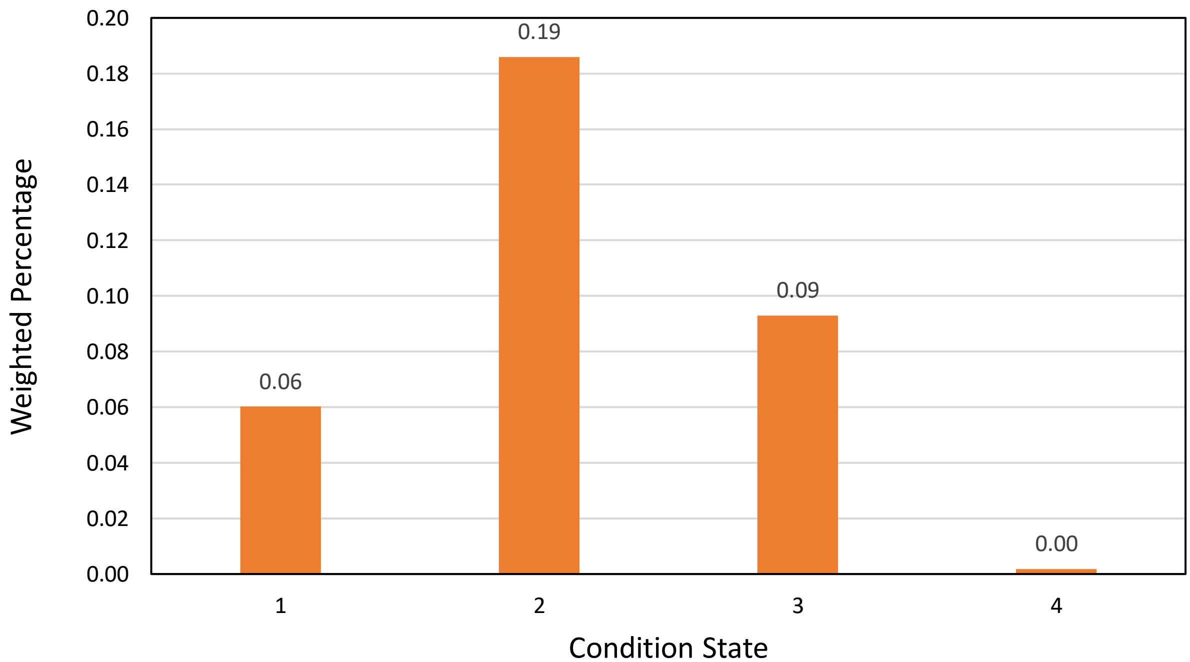


Figure E.32: Element 219, Steel Abutment Substructure (No. of Bridges = 4).

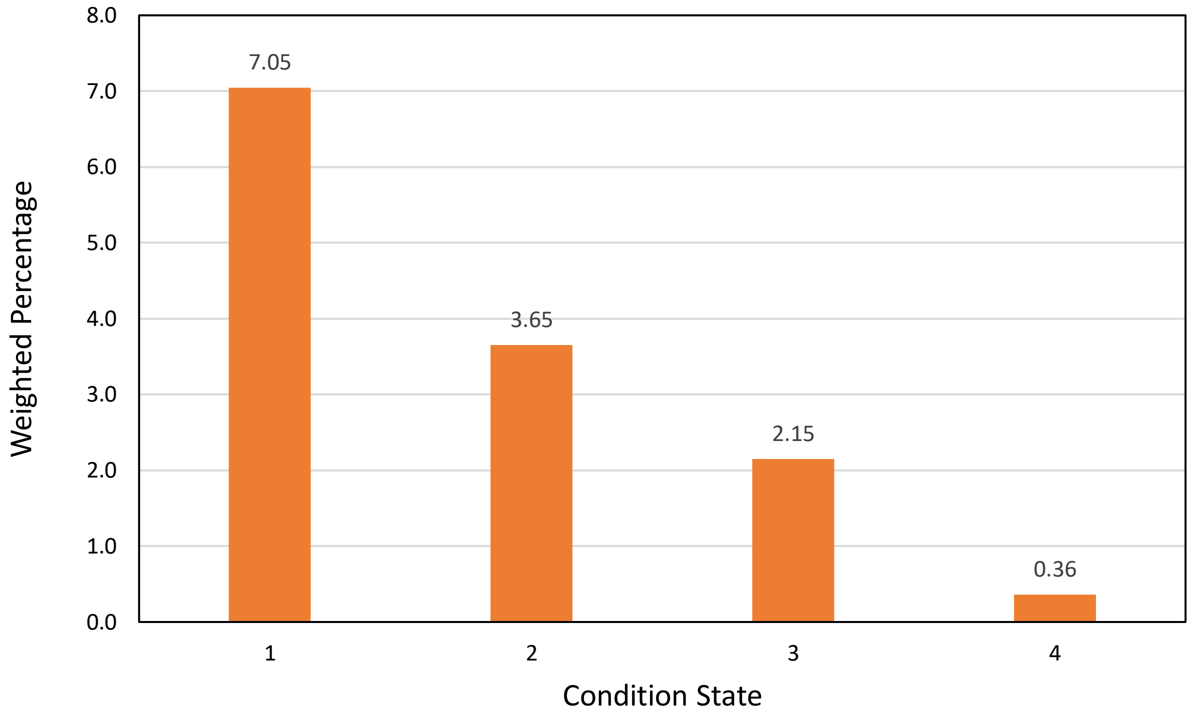


Figure E.33: Element 215, Reinforced Concrete Abutment Substructure (No. of Bridges = 155).

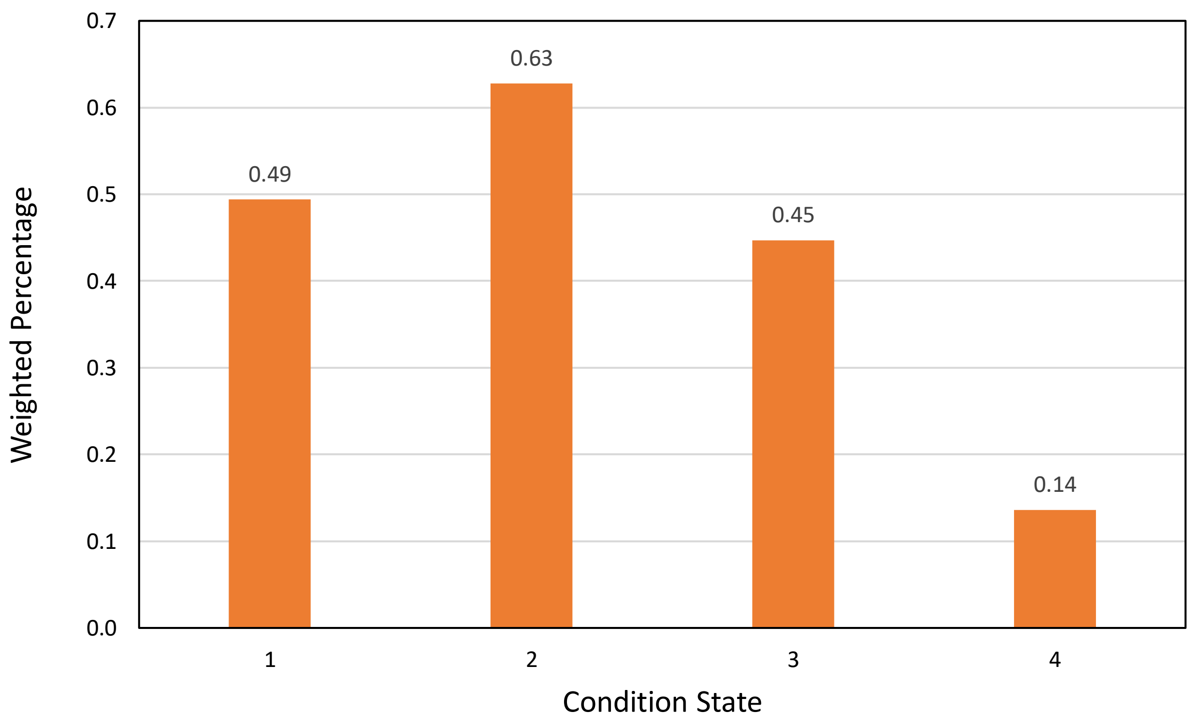


Figure E.34: Element 216, Timber Abutment Substructure (No. of Bridges = 20).

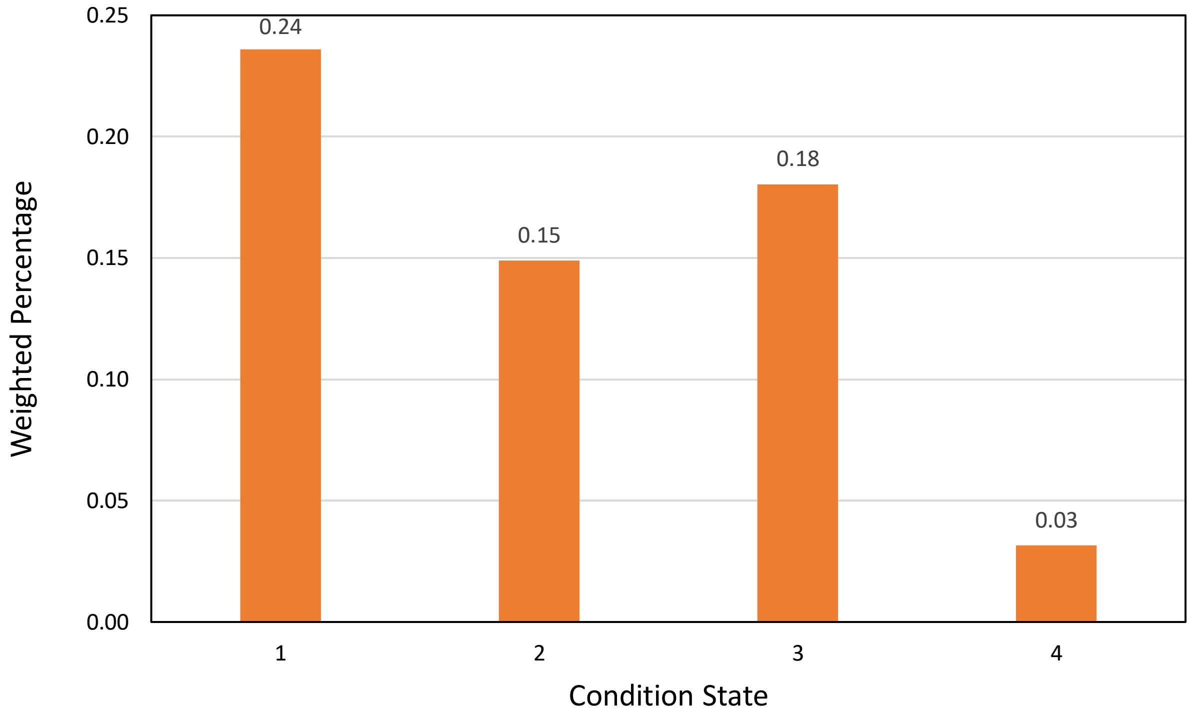


Figure E.35: Element 217, Masonry Abutment Substructure (No. of Bridges = 7).

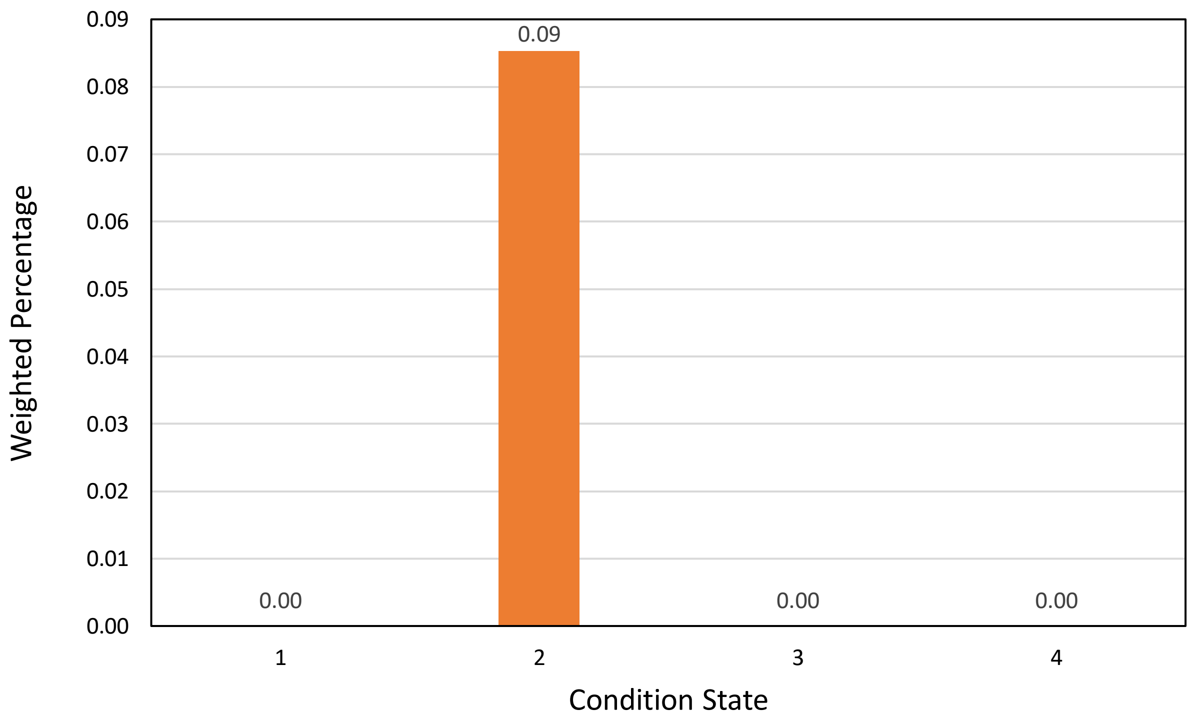


Figure E.36: Element 218, "Other Material" Abutment Substructure (No. of Bridges = 1).

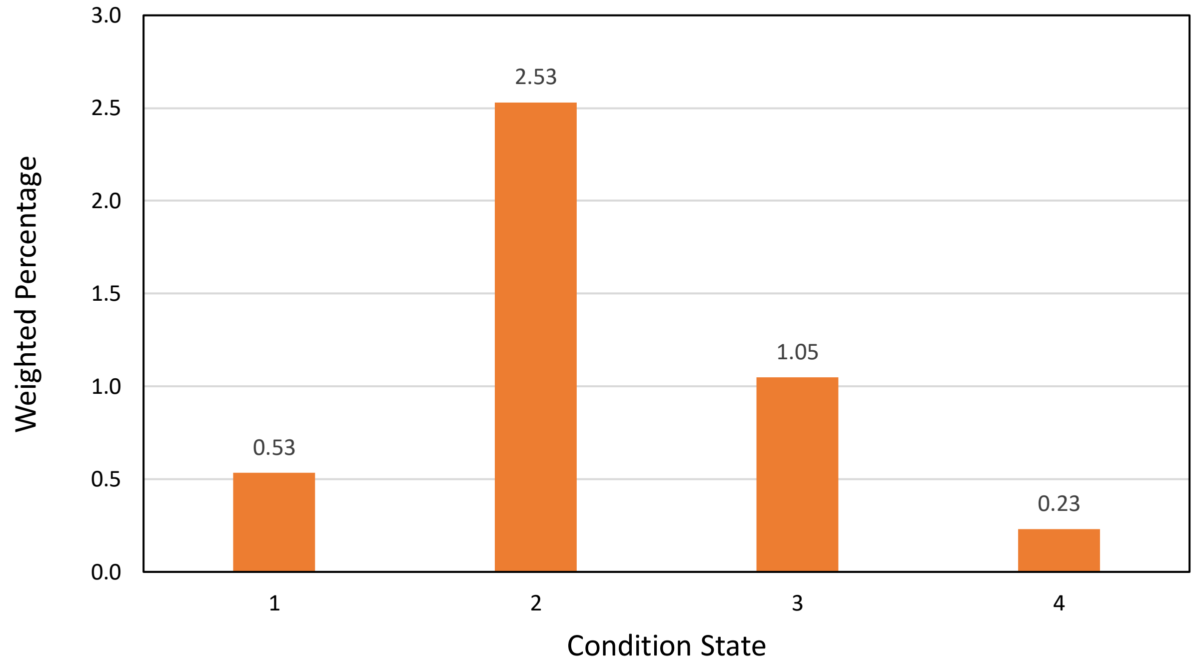


Figure E.37: Element 220, Reinforced Concrete Pile Cap/Footing Substructure (No. of Bridges = 51).

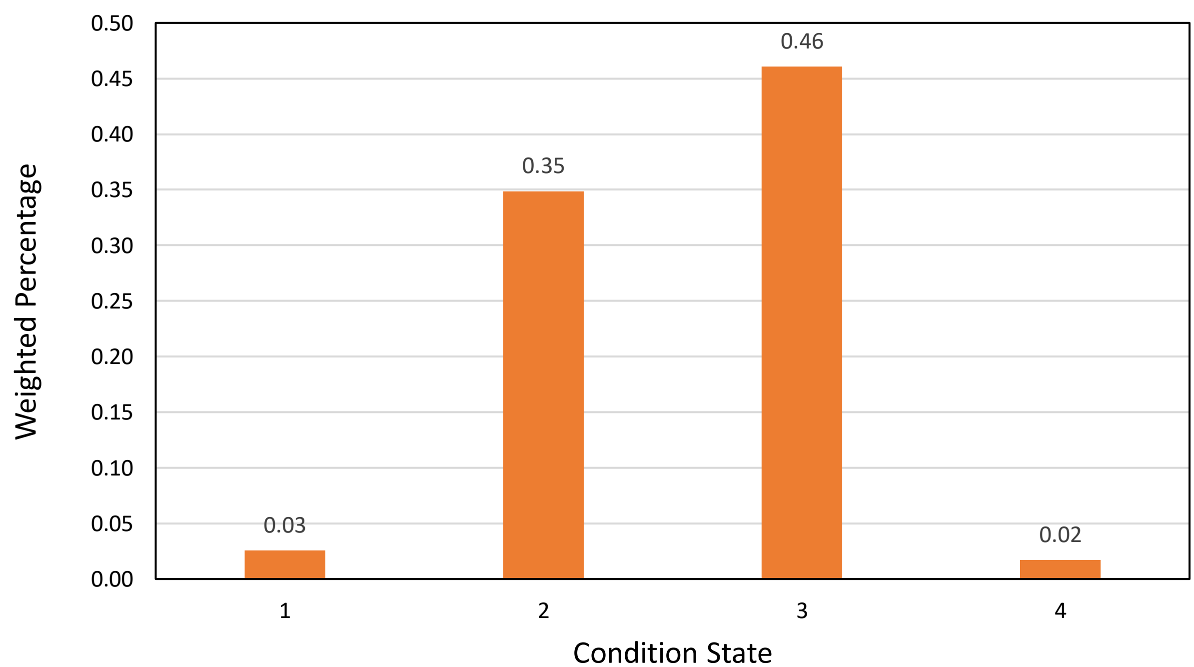


Figure E.38: Element 225, Steel Pile Substructure (No. of Bridges = 10).

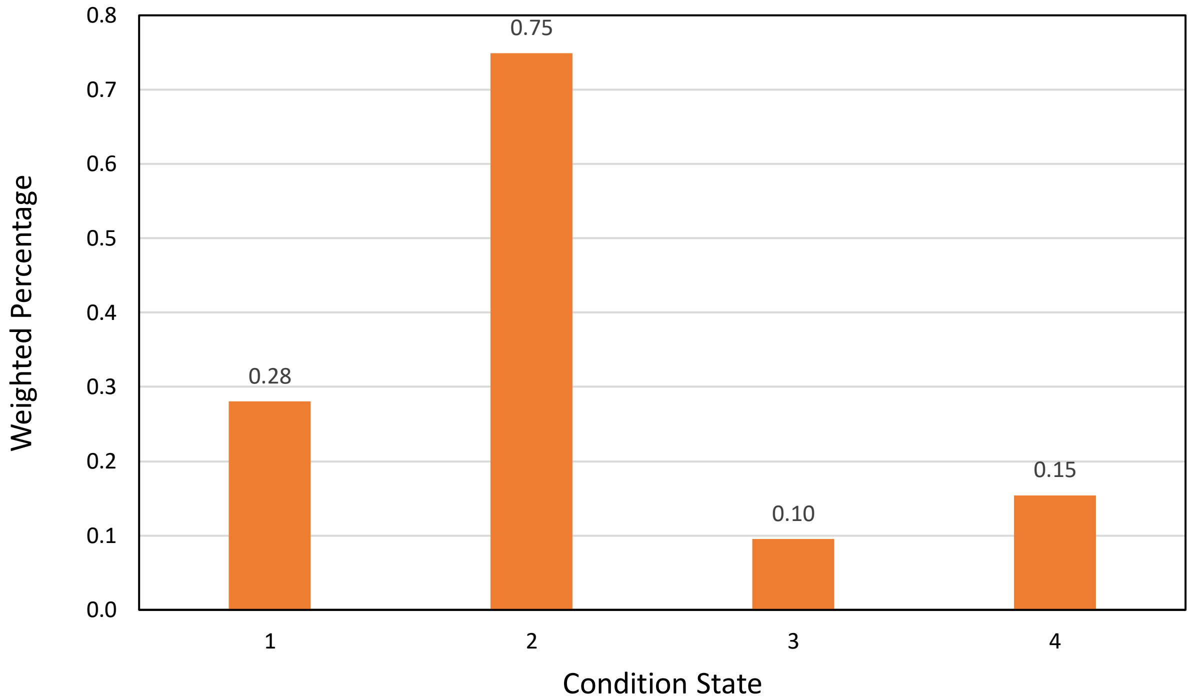


Figure E.39: Element 228, Timber Pile Substructure (No. of Bridges = 15).

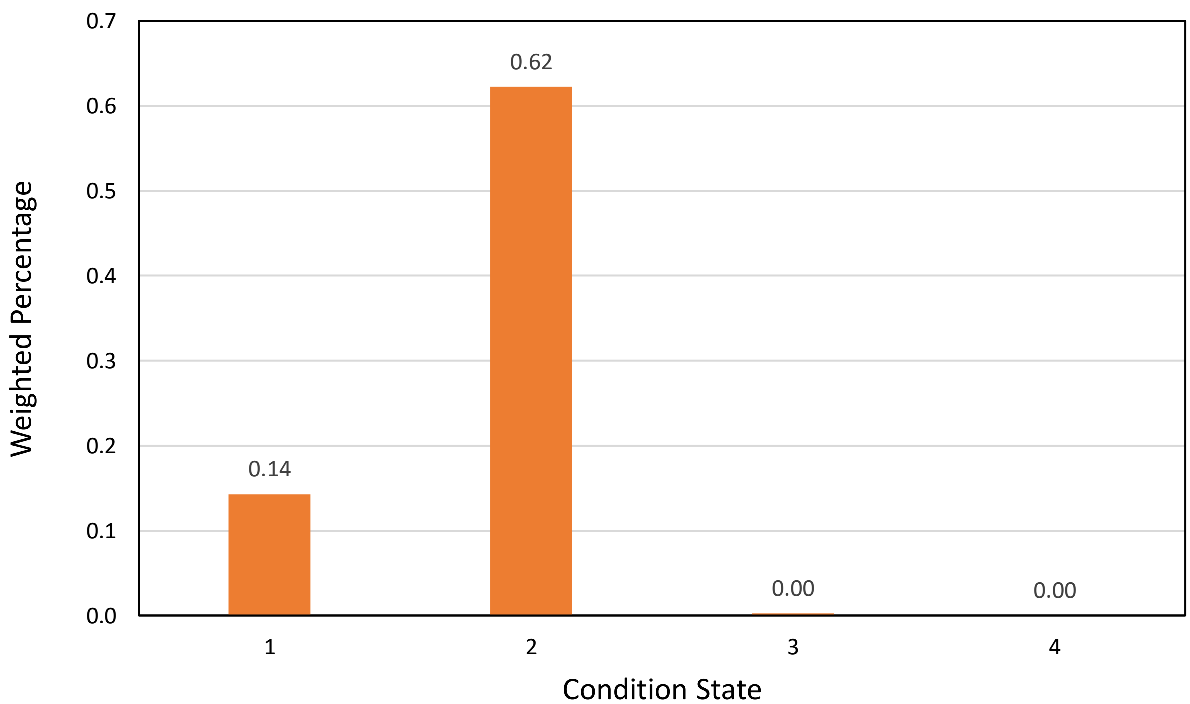


Figure E.40: Element 231, Steel Pier Cap Substructure (No. of Bridges = 9).

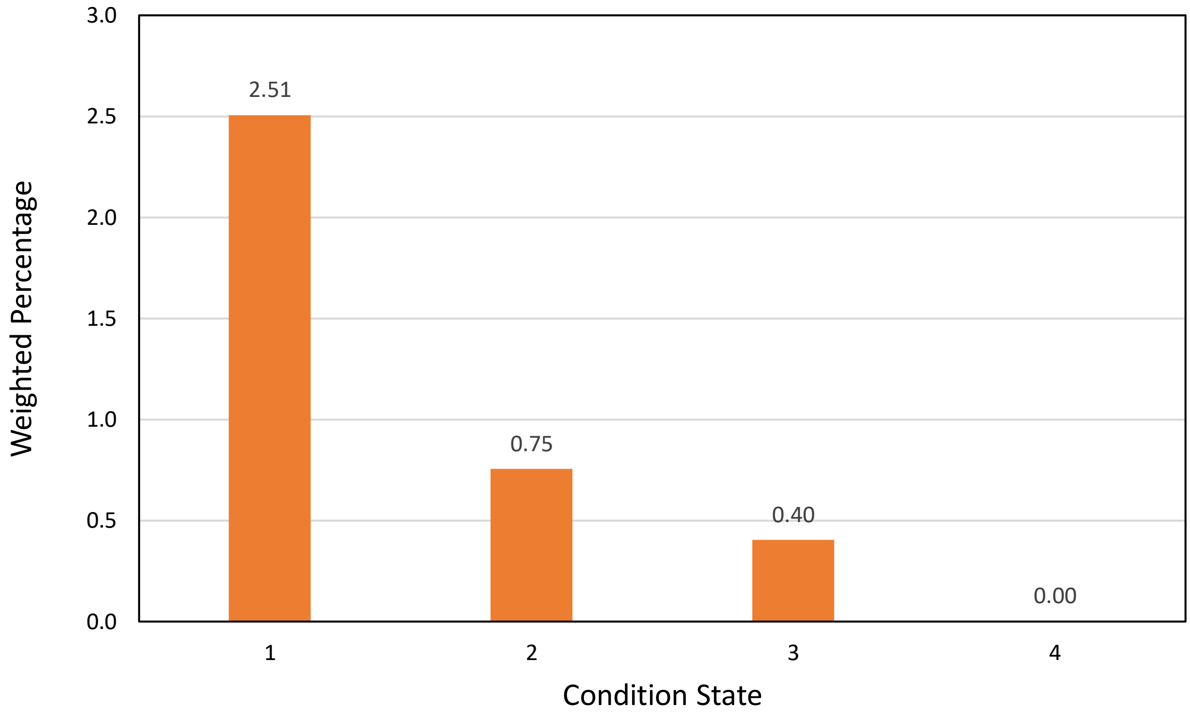


Figure E.41: Element 234, Reinforced Concrete Pier Cap Substructure (No. of Bridges = 43).

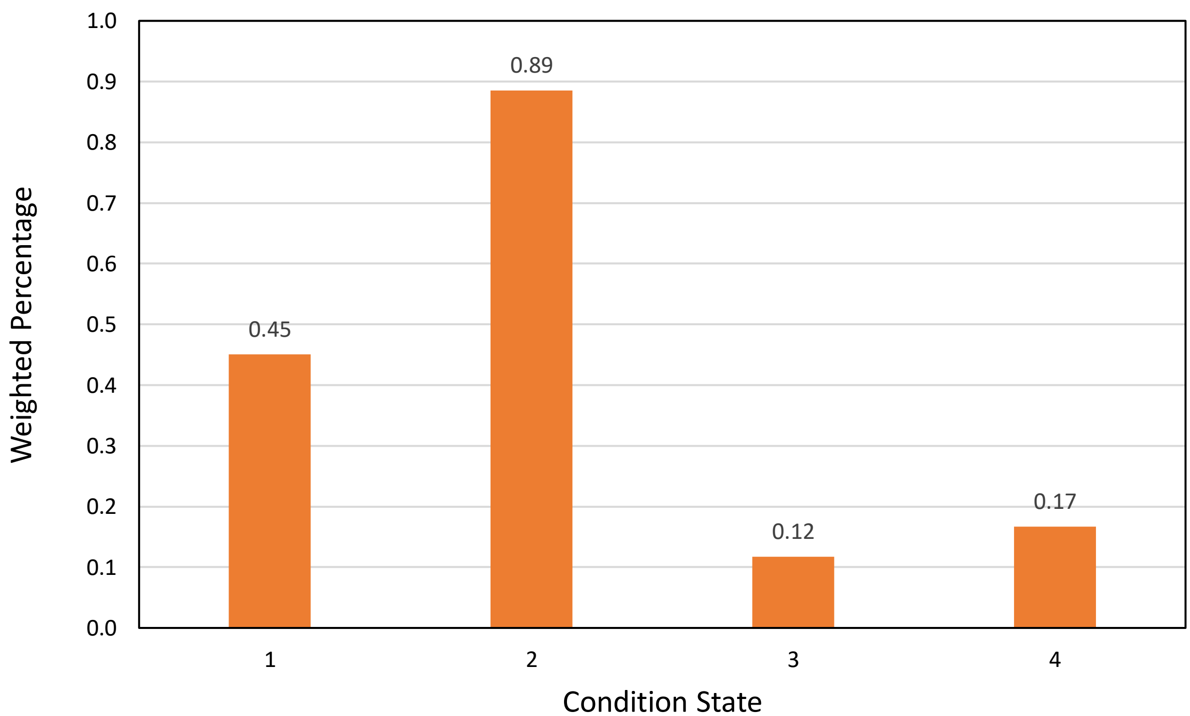


Figure E.42: Element 235, Timber Pier Cap Substructure (No. of Bridges = 19).

Culvert Elements:

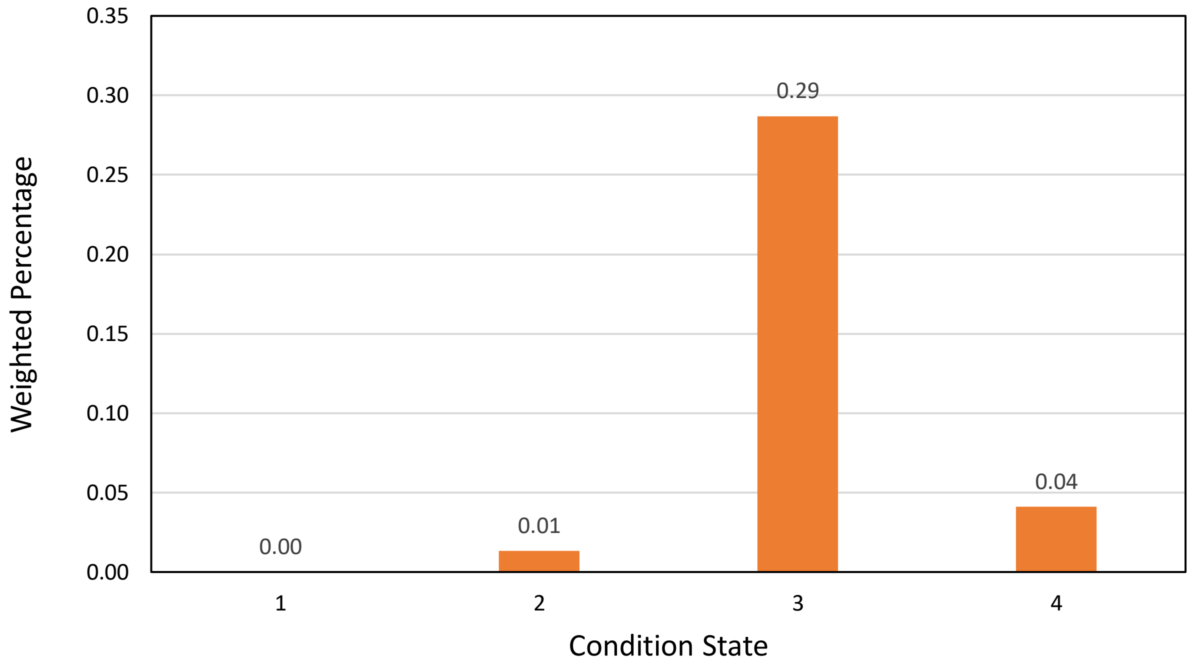


Figure E.43: Element 240, Steel Culvert (No. of Bridges = 4).

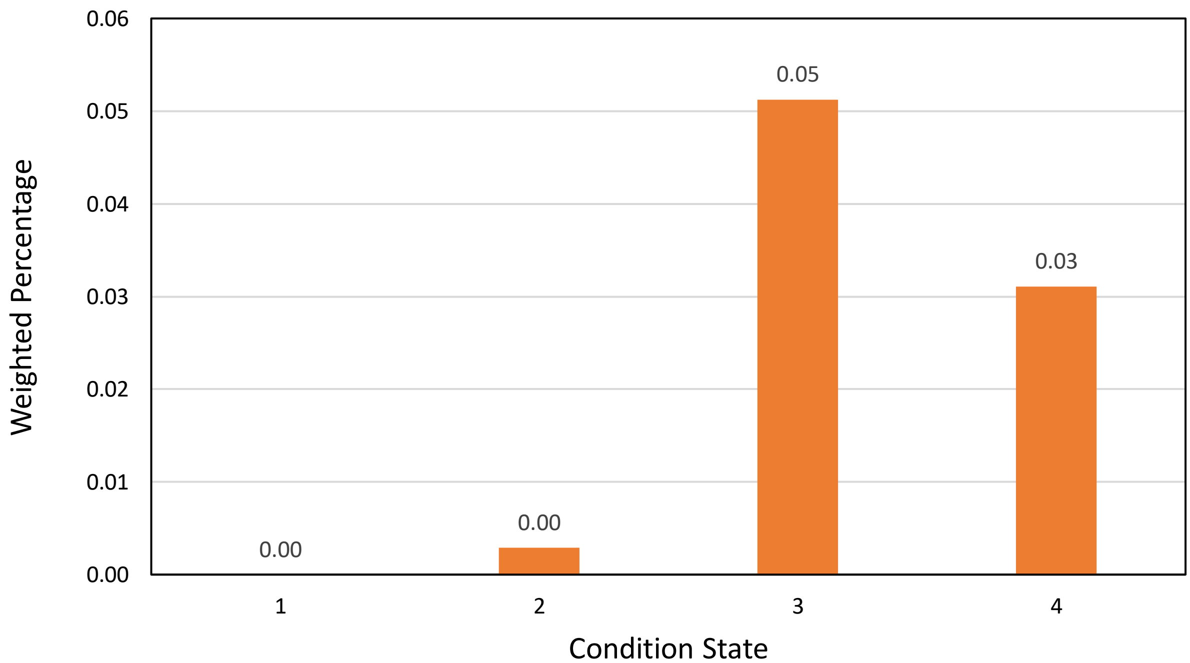


Figure E.44: Element 241, Reinforced Concrete Culvert (No. of Bridges = 1).

Bridge Rail Elements:

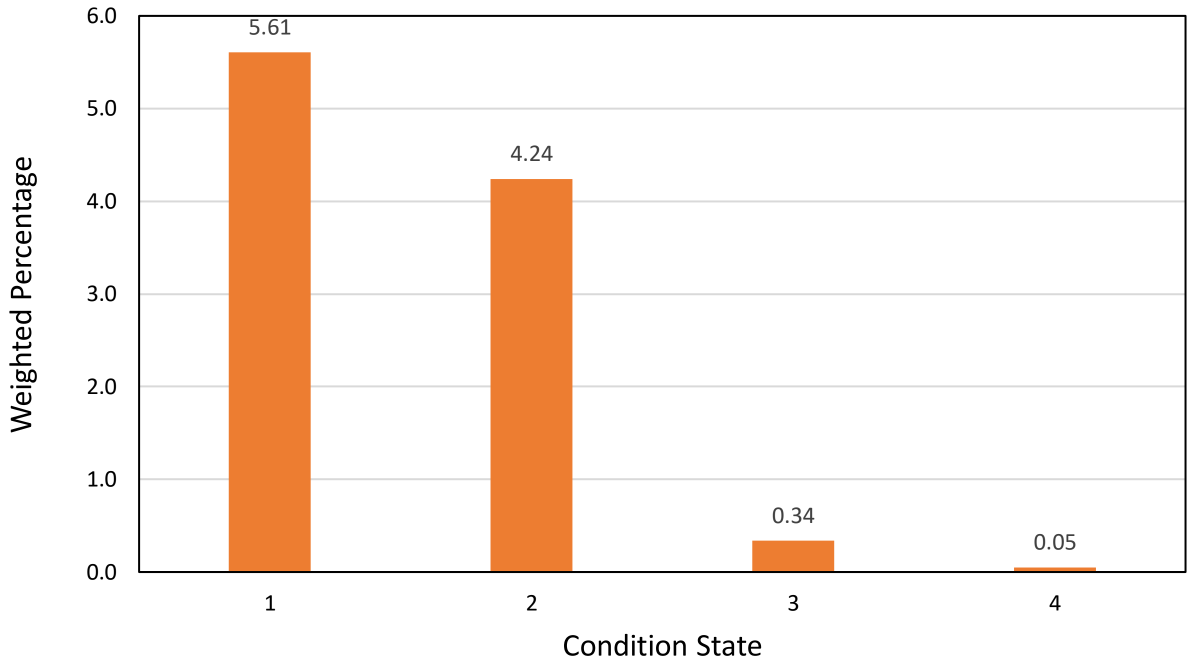


Figure E.45: Element 330, Steel Bridge Rail (No. of Bridges = 120).

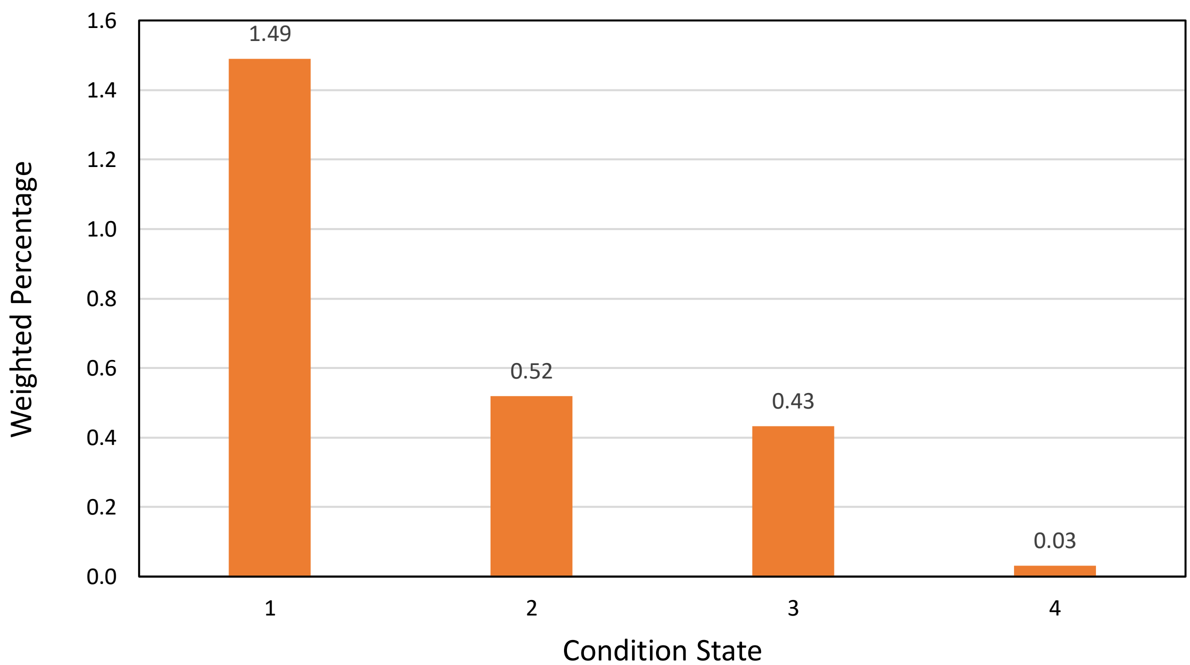


Figure E.46: Element 331, Reinforced Concrete Bridge Rail (No. of Bridges = 29).

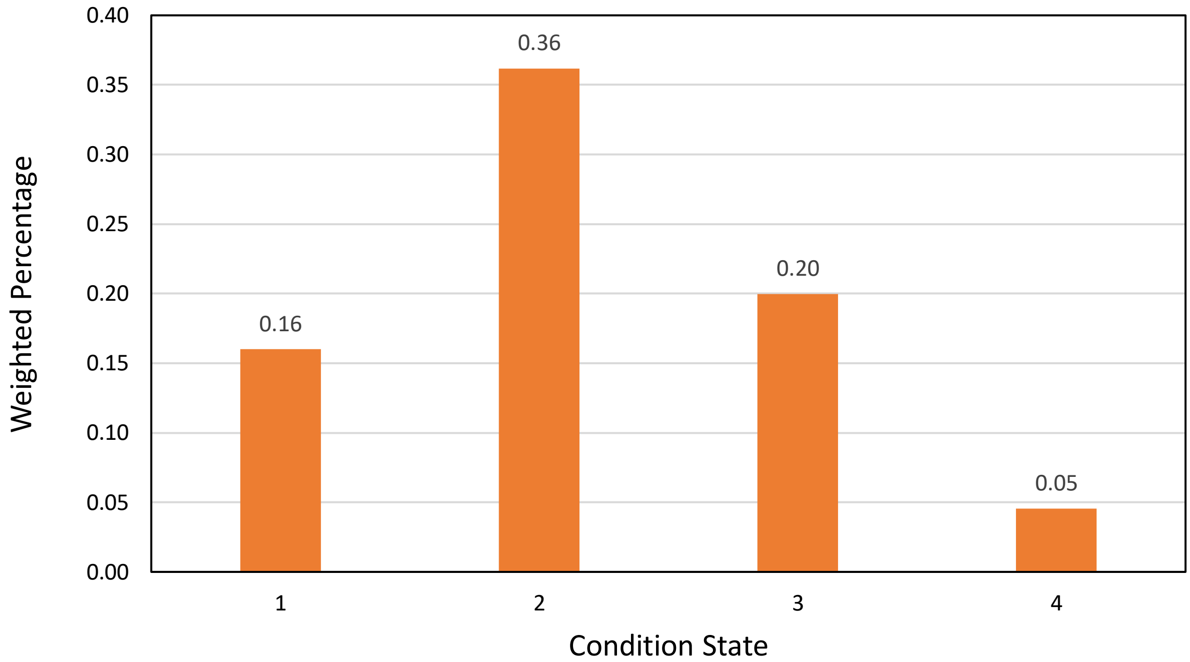


Figure E.47: Element 332, Timber Bridge Rail (No. of Bridges = 9).

Bearing Elements:

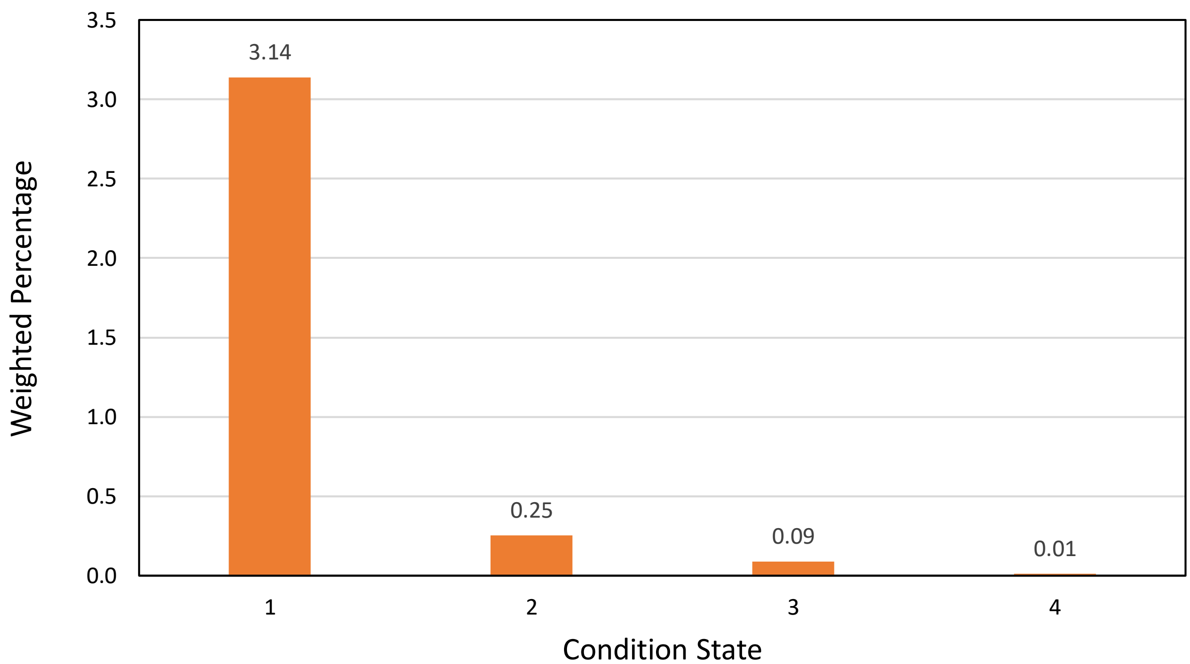


Figure E.48: Element 310, Elastomeric Bearing (No. of Bridges = 41).

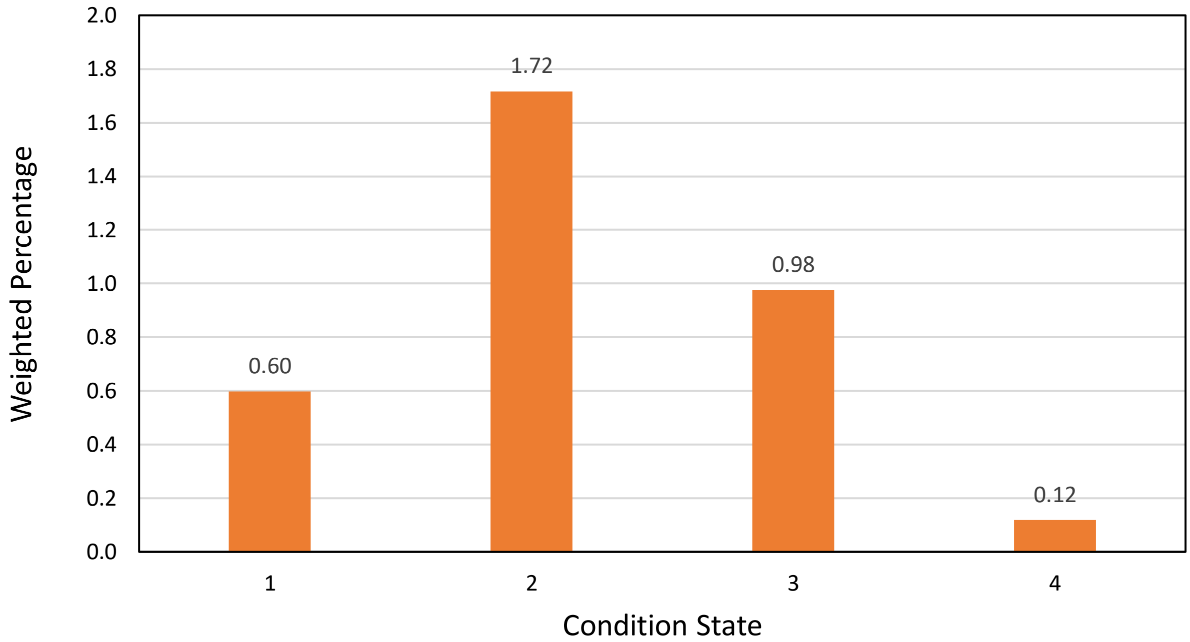


Figure E.49: Element 311, Movable Bearing (No. of Bridges = 40).

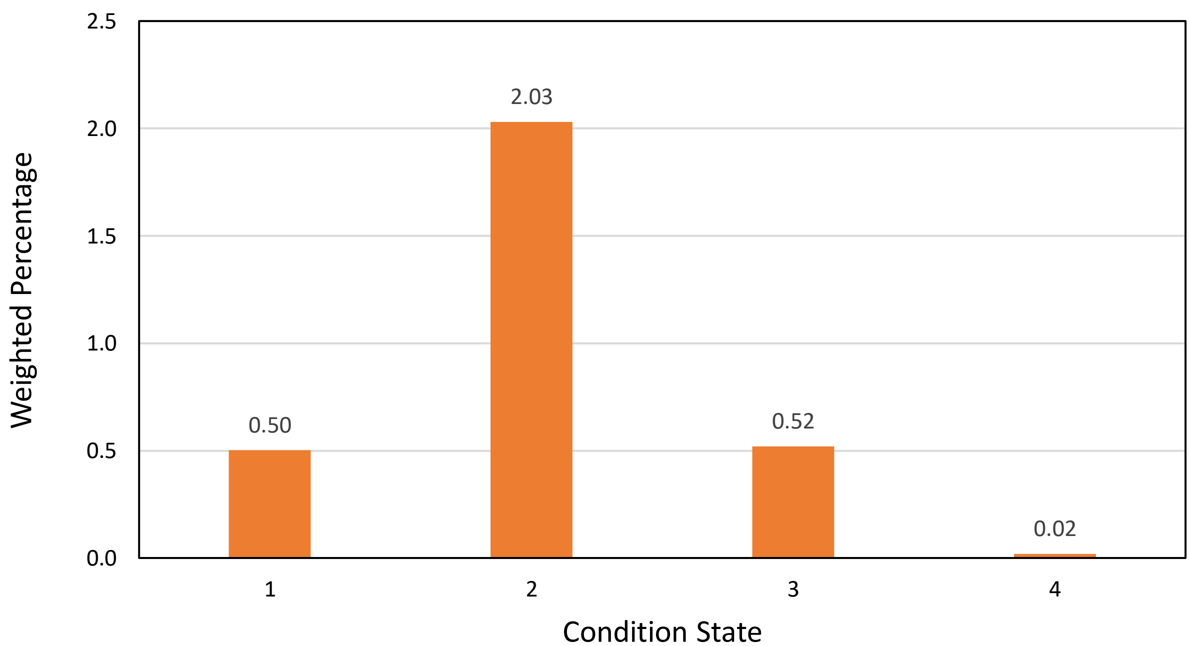


Figure E.50: Element 313, Fixed Bearing (No. of Bridges = 36).