Proceedings of the 33rd United States – Japan Bridge Engineering Workshop

David Yang

Department of Civil and Environmental Engineering, Portland State University
1930 SW 4th Avenue, Portland, Oregon 97201

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16. Abstract This report summarizes the 33rd United States–Japan Bridge Engineering Workshop, an event that convenes bridge engineers from both countries. The workshop serves as a platform to exchange innovative ideas and technologies, as well as to share crucial knowledge and lessons learned, all with the aim of advancing bridge engineering. The 33rd workshop specifically addressed transportation asset management and seismic retrofitting, two subjects of increasing importance to both the United States and Japan. The report details the workshop's discussions on topics relevant to bridge engineers.			
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
DOT	Department of Transportation
FHWA	Federal Highway Administration (U.S.)
MLIT	Ministry of Land, Infrastructure, Transport and Tourism (Japan)
NILIM	National Institute of Land, Infrastructure, and Management (Japan)
PWRI	Public Works Research Institute (PWRI)
SR	State Route
TAMP	Transportation Asset Management Plan

CHAPTER 1

INTRODUCTION

The U.S.-Japan Bridge Engineering Workshop dates back to 1984, when the first workshop took place in Tsukuba, Japan. Since then, the United States and Japan have been sharing bridge engineering knowledge through 32 joint workshops and additional virtual meetings. Carrying on this long-running tradition and successful collaboration, the 33rd U.S.-Japan Bridge Engineering Workshop was a cooperative effort between the Federal Highway Administration (FHWA) in the U.S. and the National Institute of Land, Infrastructure, and Management (NILIM) of Japan. After the 32nd workshop in Tokyo, Japan in 2023, this year's event was back in the U.S. and held in Tacoma, Washington, from August 4 to August 7, 2025. It was planned and executed in collaboration with the Washington State Department of Transportation (WSDOT), with additional support from several State DOTs.

The workshop was structured around two major topics, each with specific subtopics, summarized as follows:

- Topic 1 Bridge Inspection, Maintenance, and Post-inspection Actions
    - Topic 1A: Data-driven Actions – Preservation and Maintenance Examples
    - Topic 1B: Data-driven Actions – Guidance and Implementation Examples
    - Topic 1C, Performance and Strength Evaluation – Safe Load Carrying Capacity
    - Topic 1D: Data-driven Actions and Extreme Events Evaluation & Risk Management and Retrofitting
- Topic 2 Seismic Retrofit of Bridges and Structures
    - Topic 2A: Review of Retrofitting Methods and Programming
    - Topic 2B: Target Seismic Performance and Field Observations
    - Topic 2C: Durability and Consideration of Other Design/Maintenance Factors
    - Topic 2D: Post-event Management
    - Topic 2E: New Technology & Knowledge Update
    - Topic 2F: Research Needs/Roadmap

Additionally, the workshop included the following four site visits on August 6 and August 7:

- Fishing Wars Memorial Bridge, featuring a bridge inspection exercise by workshop participants following the U.S. and Japanese inspection standards
- Puget Sound Gateway Project
- State Route (SR) 520 Floating Bridge
- State Route (SR) 99 (Alaskan Way) Tunnel

1.1 WORKSHOP PARTICIPANTS

The workshop was attended by 36 participants, including 22 in the U.S. delegation and 14 in the Japan delegation. Participants' biographies are provided in Appendix A. Figure 1.1 features the group photograph of workshop participants.

Source: FHWA

Figure 1.1 Photograph. Workshop participants.

1.2 WORKSHOP PROGRAM

Day 1 (August 4) agenda include:

- 08:30 to 09:00 Workshop Welcome
  - Safety brief and workshop logistics by Tom Slameks (WSDOT) and Lori Porreca (FHWA)
  - Welcoming remarks by Gina Ahlstrom (FHWA)
  - Welcoming remarks by Masahiro Shirato (NILIM).
  - Review of meeting agenda and expectations by Derek Soden (FHWA)
- 09:00 to 09:30 Opening Discussion
  - U.S. lead: Soden; Japan lead: Shirato
- 09:30 to 10:30 Topic 1A, Data-driven Actions – Preservation and Maintenance Examples
  - U.S. lead: Constable; Japan lead: Nozaka
- 10:30 to 11:00 Morning break
- 11:00 to 12:00 Topic 1B, Data-driven Actions – Guidance and Implementation Examples
  - U.S. lead: Constable; Japan lead: Nozaka
- 12:00 to 13:15 Lunch break

- 13:15 to 14:30 Topic 1C, Performance and Strength Evaluation - Safe Load Carrying Capacity
    - U.S. lead: Soden; Japan lead: Fujiyama
- 14:30 to 15:00 Afternoon break
- 15:00 to 16:30 Topic 1D, Data-driven Actions and Extreme Events Evaluation & Risk Management and Retrofitting
    - U.S. lead: Soden; Japan lead: Akiyama
- 16:30 to 17:00 Open Discussion and Miscellaneous
    - U.S. lead: Soden; Japan lead: Shirato

Day 2 (August 5) agenda include:

- 08:30 to 09:30 Topic 2-A, Review of Retrofitting Methods and Programming
    - U.S. lead: Buckle, Traina; Japan lead: Ohsumi
- 09:30 to 10:30 Topic 2-B, Target Seismic Performance and Field Observations
    - U.S. lead: Yoon, Murray; Japan lead: Nakamura
- 10:30 to 11:00 Morning break
- 11:00 to 12:00 Topic 2-C, Durability and Consideration of Other Design/Maintenance Factors
    - U.S. lead: Leland, Shen; Japan lead: Hanji
- 12:00 to 13:15 Lunch break
- 13:15 to 14:00 Topic 2-D, Post-event Management
    - U.S. lead: Murray; Japan lead: Shirato
- 14:00 to 15:00 Topic 2-E, New Technology, Knowledge Update
    - U.S. lead: Mohamed; Japan lead: Akiyama
- 15:00 to 15:30 Afternoon break
- 15:30 to 16:30 Topic 2-F, Research Needs/Roadmap
    - U.S. lead: Shen; Japan lead: Shirato
- 16:30 to 17:00 Wrap-up and Future Plan

Day 3 (August 6) agenda include:

- 08:30 to 11:30 Site Visit 1, Fishing Wars Memorial Bridge: Bridge Inspection Exercise
- 11:30 to 13:00 Lunch break
- 13:00 to 16:15 Site Visit 2, Puget Sound Gateway Project

Day 4 (August 7) agenda include:

- 9:30 to 11:30 Site visit 3
    - Participants were divided into two groups
    - Group 1 went on site visit at SR520 Floating Bridge
    - Group 2 went on site visit at SR99 (Alaskan Way) Tunnel
- 11:30 to 13:00 Lunch break
- 13:00 to 15:30 Site visit 4
    - Groups switched site visit locations
    - Group 1 went on site visit at SR99 (Alaskan Way) Tunnel

- Group 2 went on site visit at SR520 Floating Bridge

1.3 OPENING DISCUSSION

Derek Soden (FHWA) led the opening discussion with an overview of pre-workshop questions collected from the U.S. delegation (questions and responses are provided in Appendix B[1]). The history and challenges related to transportation asset management (and bridge management in particular) were also briefly introduced. In the U.S., data-driven bridge management (and element-level inspection) started in early 1990s with the development of bridge management systems and element-level data specifications and was affirmed in the 2012 MAP-21 authorizing legislation which established requirements for risk-based asset management and State transportation asset management plans (TAMP). In the years since, State DOTs have developed various methods to use bridge inspection data to identify cost-effective interventions. While these approaches typically focus on condition improvement, recent bridge failures attributed to natural and man-made hazards further highlight the need for risk-based asset management. There is ongoing research to consider condition improvement and risk reduction in a comprehensive and consistent framework.

Masahiro Shirato (NILIM) followed up with the background of the pre-workshop questions from the Japan delegation. Concepts and implementation of asset management started in Japan in 2006. There is still a lack of common practice on asset management among owners. Masahiro echoed the need in Japan to coordinate the actions for condition improvement and seismic retrofitting. Challenges also exist for refining performance evaluation of existing structures and seismic retrofitting, and development of standards for reliability-based service life design, life-cycle cost analysis, and maintenance planning. In response to a question from the U.S. delegation, Masahiro clarified that Japan does not use the load rating equation commonly used in the U.S. Capacity evaluation (including earthquake resistance) is not quantified during inspection. However, bridge inspectors do use engineering judgement to estimate the seismic performance of deteriorated structures.

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[1] The questions for both topics were exchanged before the Workshop for the purpose of better understanding of the interest from each country and for the convenience of preparing presentation materials that may address these questions.

CHAPTER 2

TOPIC 1: BRIDGE INSPECTION, MAINTENANCE, AND POST-INSPECTION ACTIONS

Derek Soden (FHWA) introduced the topic, including all subtopics and U.S. members who contributed to the presentations under this topic, as shown below in Table 2.1. Derek Soden (FHWA) also provided a historical context of bridge condition data collection in the U.S, and the more recent initiatives to risk- and performance-based asset management.

Table 2.1. U.S. contributors to Topic 1.

Member	Affiliation
Harjit Bal	New Jersey DOT (NJDOT)
Derek Constable	FHWA
Evan Grimm	Washington DOT (WSDOT)
Erich Hart	Indiana DOT (INDOT)
Ed Lutgen	Minnesota DOT (MnDOT)
Philip Meinel	Wisconsin DOT (WisDOT)
Derek Soden	FHWA
David Yang	Portland State University

2.1 TOPIC 1A: DATA-DRIVEN ACTIONS – PRESERVATION AND MAINTENANCE EXAMPLES

Topic 1A included one presentation by the U.S. delegation and one presentation by the Japan delegation, followed by an open discussion. Prior to presentations, Derek Constable (FHWA) provided an overview of Topic 1A, including the benefit of data for decision support, data availability, and several challenges. Presentation slides can be found in Appendix C.

2.1.1 Wisconsin Case Studies of NDE Driven Deck Preservation — Philip Meinel (WisDOT)

The presentation detailed how Wisconsin implemented a statewide program for preservation of bridge decks, including agency defined inspection items supplemented by a non-destructive evaluation (NDE) program, and a work type decision process driven by the Wisconsin Structures Asset Management System (WiSAMS). This program helps in recommending deck preservation activities, impacting project scoping and leading to significant cost savings. The presentation covered the following key topics:

- Evolution of Wisconsin's asset management system
- NDE techniques and target elements
- Case studies of NDE-driven decisions

This data-driven approach, detailed in the presentation, highlights Wisconsin's commitment to efficient and cost-effective bridge deck preservation through systematic evaluation and informed decision-making.

2.1.2 Quantitative and Performance-Based Durability Design Based on Accumulated Condition Data — Hirohisa Koga (PWRI)

The presentation focused on quantitative and performance-based durability design for bridges, specifically addressing the issue of corrosion due to chloride ions in concrete. The presentation covered the following key topics:

- Definition and issues of durability design in Japanese code
- Corrosion of steel bars in concrete (coastal areas)
- Data-driven durability verification
- Future works, including separation of environmental and resistance factors and adapting to new survey techniques.

The presentation concluded that bridges built under current Japanese regulations are estimated to have close to a 97% probability of not initiating deterioration for 100 years, even in salt-prone areas. However, further data accumulation and more detailed information (like concrete composition) are necessary for quantitatively demonstrating reliability. While inspection data is valuable for its large volume, it often lacks the detailed information needed for in-depth analysis.

2.1.3 Open Discussion

Discussions focused on asset management and service life design, covering various topics. Communicating to engineers and leadership the value of data collection, asset management, and NDE techniques was acknowledged in both delegations. Japan's concrete cover requirement (especially near coasts) and its ongoing development of service life and asset management standards were noted. The frequency and validation of Non-Destructive Evaluation (NDE) were discussed, with frequencies currently based on engineering judgment and prior inspection results.

The conversation then shifted to new technologies and data accuracy, touching on recent research on weathering steel and the application of machine learning and AI to improve interpretation of NDE data. Usability of data and handling outliers were identified as crucial concerns, impacting costly engineering decisions. While presentations were focused on decks due to their traffic impact and data availability, other structural elements should also be considered for data-driven decisions. The advice was given to collect as much data as possible, but to start small and continuously validate data for predictive modeling.

2.2 TOPIC 1B: DATA-DRIVEN ACTIONS - GUIDANCE AND IMPLEMENTATION EXAMPLES

Topic 1B included two presentations from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Prior to the presentations, Derek Constable (FHWA) provided a short introduction to bridge data, metrics, and analysis in support of network- and bridge-level asset management. Presentation slides can be found in Appendix C.

2.2.1 Indiana DOT Bridge Asset Management — Erich Hart (INDOT)

The presentation provided an summary of Indiana's bridge assets, budget, planning processes, and the role of INDOT's asset management software. The presentation covered the following key topics:

- INDOT bridge assets districts and bridge preservation budget
- District budget target and planning, focusing on trade-off analysis using 20- and 40-year projections and deviation rules.
- Asset management software, limitations, and keys to successful implementation

The presentation also highlighted challenges, including integrating additional work types and ancillary work types, developing better deterioration curves, improving the benefit/objective function (allowing for risk-based components), incorporating element-level inspection data, and incorporating additional risk elements.

2.2.2 Bridge Management Plan for Individual Bridges — Ed Lutgen (MnDOT)

The presentation discussed when bridge management plans for individual bridges might be appropriate, emphasizing that individual bridge plans offer a matrix of detailed options and recommendations for future projects. Specifically, the presentation covered:

- Individual bridge management plans and evaluation
- Possible actions, recommendations, and design tools
- Case study on the Dunwoody Bridge in Minnesota

2.2.3 Performance and Damage Data Collection in Bridge Inspection — Masahiro Shirato (NILIM)

The presentation focused on the performance and damage data collected from bridge inspection in Japan. Key topics covered include:

- Bridge inspection record structure in Japan implemented in 2006.
- Damage/symptom recording and performance evaluation: Japan uses a segmental data recording system where structural members are subdivided into Data Recording Segments (DRSs).
- Data analysis and issues in data usage, such as the need for a standardized Life Cycle Cost (LCC) calculation protocol, clear use cases for calculated performances and LCCs.

NILIM provides online access to MS-Excel files containing more than 250 types of transition probability matrices and average deterioration curves, allowing bridge owners to compare their bridge conditions to national averages. The importance of demonstrating the benefits of detailed data recording for sustainability was also emphasized.

2.2.4 Open Discussion

Key discussion points include:

- Inspector qualification: There is no national qualification or certification required for bridge inspectors in Japan. Certification is required for U.S. bridge inspectors, but an engineering degree isn't necessary for those working in the field.
- Practical implementation of objective, segmental data collection: In Japan, an inspector records the location of the damage, and the location is later processed and assigned to the specific element number. The U.S. is interested in such spatially segmented models to improve bridge management including deterioration forecasting and data driven scoping and benefit-cost analysis. BrIM (Bridge Information Models) could be a useful tool for this purpose.
- Contrast between Japan's segmental data recording system and the U.S.'s NBE system and the NBI rating.
- Comparisons of Japan's 5-year inspection cycle and the U.S.'s 2-year cycle: It was clarified that Japan's 5-year cycle aligns with many other planning activities in Japan, and deterioration data can support this interval.

2.3 TOPIC 1C: PERFORMANCE AND STRENGTH EVALUATION - SAFE LOAD CARRYING CAPACITY

Topic 1C included one presentation from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Prior to the presentations, Derek Soden (FHWA) briefly introduced the background, relevant regulations, use cases, perceived benefits, and challenges related to the practice of load rating in the U.S. Presentation slides can be found in Appendix C.

2.3.1 Bridge Load Rating — Ed Lutgen (MnDOT)

The presentation covered various aspects of bridge load rating, including:

- Rating basics, rating vehicles, rating timing, and requirements
- Load permitting, bridge posting, and signage
- Above legal load permitting: in 2024, MnDOT processed 150,000 permits.
- Challenges in load rating, such as risk of side-by-side permit truck, detouring of permitted trucks, and rating of unique structural types such as culverts.

The presenter also shared example forms for the MnDOT Bridge and Load Posting Report, MnDOT's experience with automated rating for permitting, a public-facing website for fire truck routes, and MnDOT's posting flow charts.

2.3.2 Development of Repair and Rehabilitation Design Codes for Road Bridges — Eisuke Nakamura (PWRI)

The presentation discussed the challenges and advancements in developing design codes for evaluating, repairing, and rehabilitating existing road bridges in Japan. The presentation included the following discussions:

- Background, motivation, and objectives of the design code under preparation
- Bridge performance targeted: load-carrying capacity, durability, and functionality

- Feasibility and trade-offs of modifying load or resistance factors
- Challenges encountered, including existing bridges vs. new design, reference period for different performance targets, and utilization of site- and structure-specific information

2.3.3 Open Discussion

The discussion centered on bridge load rating, structural evaluation, and the development of design codes for the repair and rehabilitation of existing bridges, drawing perspectives from both Japan and the United States. Key discussions from both sides include:

- Load rating, as it's understood in the U.S., is not conducted in Japan. Currently, load-carrying capacities are analyzed by moment and shear diagrams caused by design vehicles. Condition data provide an incentive to have a detailed load rating procedure/guide.
- In Japan, parapet may be considered in the calculation of load-carrying capacity. This is not the case in the U.S. due to the concerns of vehicle collisions resulting loss of parapets.
- The U.S. uses a condition factor to discount resistance based on National Bridge Inventory condition rating, however, these condition factors are not calibrated.
- The U.S. allows the use of site-specific load factors based on the site weigh-in-motion (WIM) data.
- Sometimes, a rating factor equal to 0.9 is accepted if the remaining service life is low.

2.4 TOPIC 1D: DATA-DRIVEN ACTIONS AND EXTREME EVENTS EVALUATION & RISK MANAGEMENT AND RETROFITTING

Topic 1D included two presentations from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Prior to the presentations, Derek Soden (FHWA) briefly introduced the seismic evaluation process, screening methods, and seismic and vessel collision screening currently in use in the U.S. Presentation slides can be found in Appendix C.

2.4.1 Risk Assessment for New Jersey Bridges — Harjit S. Bal (NJDOT)

This presentation discussed New Jersey's risk assessment approach for its bridge assets. Key points from the presentation include:

- Key facts about New Jersey's bridge infrastructure
- NJDOT's risk assessment approach and development history
- Components of the risk assessment framework, including data acquisition and software implementation
- Example of a fatigue risk assessment

The presentation noted that the criteria weighting is subject to review and revision by NJDOT. The final risk scores are used for screening and prioritization and can be tracked over time to assess the impact of different mitigation strategies. The framework is being revised continuously, e.g., NJDOT is considering using skew instead of skew index for fatigue risk assessment.

2.4.2 Seismic Retrofit: Washington State's Program — Evan Grimm (WSDOT)

The presentation outlined various retrofit techniques for both the superstructure and substructure, and provided an overview of the program's progress and limitations. Key points from the presentation include:

- WSDOT's retrofit techniques for superstructure and substructure
- Retrofit design standards: primarily use the FHWA 2006 manual (FHWA, 2006) but adopt newer ground motion.
- Program details, program structure, and three program phases: the budget for seismic retrofitting is smaller than that for condition improvement.
- Muti-agency program focused on retrofitting seismic lifelines
- Latest progress in terms of identified bridges, completely/partially retrofitted bridges, and total expenditures

It is noted that the program's core objective is to prevent structural collapse and minimize loss of life and commerce by prioritizing retrofit projects. Moderate damage may be accepted. Limitations also exist, such as not being able to adequately address liquefaction or guarantee quick and full post-earthquake operation.

2.4.3 History of Disaster Mitigation and Prevention Programs and Development of Risk Management — Tomohiro Ninomiya (PWRI)

The presentation provided a historical overview of disaster mitigation and prevention programs in Japan. It highlighted the country's national resilience plans and a new, risk-based approach to road and bridge management. Key points from the presentation include:

- Japan's vulnerability and recent disasters, including both seismic and non-seismic events
- National resilience plans and budget measures, with a long-term goal of restoring essential road networks to service within one day for emergency vehicles and one week for all vehicles
- Disaster mitigation and risk management measures, including road disaster prevention inspection, road risk assessment, and road clearing plans

The presentation emphasizes a shift from reactive disaster response to proactive, data-driven strategies aimed at minimizing closures and enabling rapid recovery.

2.4.4 Open Discussion

The discussions highlighted that both the U.S. and Japan face challenges in balancing condition improvement and risk mitigation for their infrastructure networks. Key discussions from both sides include:

- Seismic inspections and retrofitting: The discussion covered the frequency of seismic safety inspections in Japan (typically 2-3 times every 10 years) and the rationale behind WSDOT's prioritization of low-cost retrofitting options (high cost-effectiveness under budget constraints).

- Funding challenges: Limited funding for condition preservation and risk mitigation poses a challenge. Risk-based approach provides a potential to coordinate both needs.
- Seismic resilience of transportation systems: Japanese design code has ductility limits for bridges tied to repair time. However, eliminating plastic damage can be costly. The U.S. design code is based on life safety. Resilience is normally assessed at the network level based on functionality, but there are computational challenges.
- Structure details of retrofit measures: The group discussed the purpose of cross cables at in-span hinges used in WSDOT retrofitting projects. WSDOT used this configuration to address longitudinal and transverse displacement, but more study is needed to demonstrate its effectiveness.
- Load path redundancy: The conversation touched on non-redundant two-girder systems and the role of bracing in providing redundancy. Lateral bracing was mentioned as not typically being a factor in load path redundancy, though a more refined analysis might be needed.
- Geotechnical considerations: The discussion recognized the importance of geotechnical issues during retrofitting design, including liquefaction and transfer of damage from the retrofitted structure to embankment.

2.5 TOPIC 1 SUMMARY AND OPEN DISCUSSION

Derek Soden (FHWA) summarized the presentations and the discussion carried out under the Day 1 topic. An open discussion ensued from both delegations, focusing on items that can benefit from bilateral collaboration and joint investigation. These include:

- Segmental condition inspection: how to effectively and efficiently set up and identify segments during inspections; extension to different bridge components; full utilization of segmental condition data (e.g., during load rating); quantification of benefit for segmental data collection; addressing implementation challenges and solutions.
- Corridor-based vulnerability assessment and inspection: comparing practices from both countries can be beneficial; there is need for coordination between retrofitting and condition improvement actions; exploring risk-based asset management methods to coordinate different needs and save resources
- Performance targets for asset management: how to tie asset management performance targets to targets of load-carrying capacity (rating factors), durability, and life-cycle cost.
- Load rating of deteriorated bridges: how to incorporate inspection results with load rating and the design and evaluation of structural retrofitting.
- Guide for data-driven actions and decision-making: how to leverage the gathered inspection results and institutional knowledge/experience to create guides or standards for bridge management
- Integrating retrofitting and condition preservation: retrofit design should also consider non-seismic events, most notably floods and storms.

CHAPTER 3

TOPIC 2: SEISMIC RETROFIT OF BRIDGES AND STRUCTURES

Jerry Shen (FHWA) led the session with self-introduction by workshop participants. He also introduced Topic 2 and all the subtopics. The U.S. members who contributed to the presentations under this topic are listed in Table 3.1. He followed up with the historical context of the topic by summarizing the FHWA seismic design/retrofit program milestones.

Table 3.1. U.S. contributors to Topic 2.

Member	Affiliation
Ian G. Buckle	University of Nevada, Reno (UNR)
Andrew Fiske	Washington DOT (WSDOT)
Amy Leland	Washington DOT
Lee Marsh	WSP
Khalid Mohamed	FHWA
Tom Murphy	Modjeski & Masters
Nick Murray	Alaska DOT&PF
Albert Nako	Oregon DOT (ODOT)
Jerry Shen	FHWA
Chris Traina	California DOT (Caltrans)
David Yang	Portland State University
Tony Yoon	California DOT (Caltrans)

3.1 TOPIC 2A: REVIEW OF RETROFITTING METHODS AND PROGRAMMING

Topic 2A included one presentation from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Presentation slides can be found in Appendix D.

3.1.1 FHWA and State Seismic Retrofitting Processes — Ian Buckle (UNR) and Christopher Traina (Caltrans)

The first part of the presentation, presented by Ian Buckle (UNR), detailed FHWA's seismic retrofitting manual for highway structures, emphasizing its advisory nature (States can adapt to their own needs) and performance-based approach. It outlined the process of screening, evaluating, and designing retrofits for bridges, guided by the Seismic Retrofit Category (SRC) assigned for different earthquake levels, bridge types, and remaining service life to achieve specific performance objectives, such as life safety or full operation. The presentation also touched on various methods for prioritizing retrofit needs and different strategies, approaches, and measures for effective retrofit design. Special emphasis was given to the consideration of remaining service life and the use of principles of bridge management systems (BMSs).

The second part of the presentation was presented by Christopher Traina (Caltrans). It outlined the Caltrans seismic retrofit process for bridges, focusing on a structured approach from initial screening to design solutions. It detailed how past earthquake events (e.g., the San Fernando Earthquake in 1971, investigated through the Post-Earthquake Investigation Teams--PEQIT) have shaped screening activities and led to the development of updated policies and guidance for seismic retrofitting. A revised retrofit guidance is currently under preparation by Caltrans. The presentation also mentioned the importance of managing public expectations regarding bridge performance during seismic events, leveraging special events such as Earthquake Awareness Month in California. A key message to convey is that while bridges may exhibit plasticity during an earthquake, this is often a designed and acceptable outcome, indicating a design success in preserving life safety rather than a failure. To ensure a successful bridge retrofit program, it is also essential to align the established goals, anticipated outcomes, and project schedules.

3.1.2 Brief History, Current Program, and Guidance — Akiko Hiroe (PWRI)

This presentation outlined the evolution of seismic design and retrofit measures for bridges in Japan, highlighting key historical earthquakes and subsequent revisions to design specifications. It detailed the progression of seismic vulnerability inspections and the shift towards more comprehensive retrofit programs. The presentation concluded by discussing recent initiatives and lessons learned from the 2024 Noto Peninsula Earthquake. Key points of the presentation include:

- Japan's seismic design standards have evolved significantly since 1923.
- Initial inspections focused on preventing critical bridge collapse.
- The 1995 Kobe earthquake spurred intensive retrofit programs.
- Retrofitting shifted to a whole-bridge, performance-based approach.
- Recent efforts address displacement restraint and repeated earthquakes (considering foreshocks and aftershocks).
- Secondary damage to the roadway underneath was discussed.

3.1.3 Open discussion

During the open discussion, a question was raised about the exemption for life-safety when a bridge has a short remaining service life and how this affects public perception. It was explained that this situation may occur when reconstruction is slated for a bridge in 9 to 10 years, and temporary retrofitting may still be conducted before reconstruction despite the exemption. It was noted that Seattle might have experience retrofitting bridges that are over 75 years old. The owner of the bridge has discretion over the remaining service life and criticality of a bridge, and public perception is used to set targets for seismic retrofit. It was also mentioned that communication on this topic can be challenging. One participant stated that the life-safety exemption clause is beneficial for a quick screening process for seismic retrofit prioritization.

3.2 TOPIC 2B: TARGET SEISMIC PERFORMANCE AND FIELD OBSERVATIONS BRIEF PRESENTATIONS

Topic 2B included one presentation from the Japan delegation and one presentation from the U.S. delegation, followed by an open discussion. Presentation slides can be found in Appendix D.

3.2.1 Performance of Retrofit Measures in Actual Events and Challenges in Recent Events — Jinsei Kuwano (PWRI)

This presentation covered the evolution of retrofit methods following major earthquakes and analyzed how these methods performed in recent seismic events, including the 2011 Tohoku, 2016

Kumamoto, 2022 Fukushima, and 2024 Noto Peninsula earthquakes. The presentation highlighted both successful applications and areas where further challenges exist regarding bridge structural integrity. Key points of the presentation include:

- Review of retrofit methods used in Japan, including reinforced concrete (RC) jackets, fiber reinforced polymer (FRP) jackets, and unseating prevention devices
- Effectiveness of seismic reinforcement that has protected bridge columns from damage
- Damage to bearings and foundations in retrofitted bridges
- Instances of failure of lateral displacement-restraining devices in many recent earthquakes
- Future challenges, including anticipating where new or transferred damage will occur after retrofit.

In conclusion, seismic retrofitting of RC piers has proven effective in mitigating damage. However, more research is needed for the proper placement of lateral displacement restraining devices. Strengthening one part of a structure can transfer vulnerabilities, causing damage to occur in other, relatively weaker areas.

3.2.2 Unmet Performance Targets — Tony Yoon (Caltrans)

This presentation detailed the seismic retrofit of bridges and structures, discussing past efforts, current challenges, and observed performance across various U.S. states. It also addressed unmet performance needs and new recommendations for improved retrofit strategies. Key points of the presentation include

- Overview of the experience related to the retrofitted bridges in western states, including Alaska, Washington, Oregon, and California. State-specific terms for performance targets like “No Collapse” uniformly signify a “life safety” design retrofit.
- Alaska witnessed prominent geotechnical failures in the 2018 Anchorage Earthquake.
- Washington and Oregon have implemented various retrofits, mainly focusing on preventing superstructure unseating.
- The California retrofit program has successfully prevented catastrophic failures in recent earthquakes.

The California program was further elaborated based on experience from four past major earthquakes. Post-earthquake, Caltrans deploys maintenance teams for safety evaluation and seismic team (Post Earthquake Investigation Team, or PEQIT) for data collection for design/retrofit revisions in the future. No major damage was observed in the four events, but the data is limited to generally earthquakes below the design-level intensity. The efficacy of retrofits in design-level earthquakes has yet to be tested. Seismic inspection has transitioned from manual to drone-based inspections.

3.2.3 Open Discussion

It was noted in the open discussion that there were no major differences in the types of damage observed from different kinds of earthquakes, such as pulse-like or long-duration events. However, long-period structures and shear keys were identified as being more vulnerable to long-duration earthquakes. There is ongoing conversation in Japan about damage due to fore- and aftershocks, such as the plasticity of columns and the effect of cover concrete. Nonetheless, no changes to detailing are planned, because low-cycle fatigue damage was not prevalent, indicating that Japan's current standards already account for multiple loading cycles in long-duration earthquakes and fore/aftershocks.

The discussion also addressed the issue of repeated bearing failures observed in Japan, suggesting it may have been due to a past subsidy program that only funded restoration to previous performance levels rather than improvement. This program has since been changed. Finally, the "unzippering" failure of shear keys, seen in one of the presentations, was discussed. Both the Japanese and U.S. codes distribute seismic force equally among shear keys. It was mentioned that the damaged shear keys failed in an unexpected way due to horizontal movement, and that exterior girders functioned as stoppers.

3.3 TOPIC 2C: DURABILITY AND CONSIDERATION OF OTHER DESIGN/MAINTENANCE FACTORS

Topic 2C included one presentation from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Presentation slides can be found in Appendix D.

3.3.1 Durability and Design Factors Related to Seismic Retrofit — Amy Leland (WSDOT)

This presentation discussed durability issues and other design/maintenance factors related to seismic retrofitting of bridges and structures in the U.S. It covered specific concerns regarding deterioration of retrofit measures and their non-seismic implications (e.g., maintenance access), with a focus on addressing these issues through proper design and maintenance. Key points include:

- Contamination of friction pendulum bearings: There are concerns in Washington that water and debris in pendulum bearings may affect seismic performance. Tests in Alaska suggest that while water and debris can get into pendulum bearings (even freezing), it may not significantly affect seismic performance. The friction coefficient remains largely unchanged, and the ice thaws easily with movement.
- In Washington, Oregon, and California, viscous dampers have shown leakage and fatigue issues due to environmental exposure and vibration. In California, concrete jacketing shows cracking.
- WSDOT experience: Washington mostly used steel jacketing, sometimes FRP. Restrainer cables pose challenges for inspection and maintenance. Retrofit measures can affect other bridge components, influence scour depth and loading on foundations.

Overall, the presentation emphasized the importance of considering long-term durability, inspectability, and serviceability when implementing seismic retrofit measures. Issues like bearing contamination, damper leakage, and concrete jacket cracking highlight the need for robust design and consistent maintenance to ensure the effectiveness and longevity of seismic retrofits. Structural responses under other loads may also be altered due to seismic retrofitting actions.

3.3.2 Deterioration and Damage to Seismically Retrofitted Bridges — Masahiro Shirato (NILIM)

This presentation discussed the deterioration and damage observed in seismically retrofitted bridges in Japan. It examined specific cases of steel arch and reinforced concrete bridges that experienced issues after seismic retrofitting. Key points include:

- A bridge retrofitted in 2007 with buckling restrained braces (BRB) and hydraulic dampers showed fatigue cracks by 2013. A bypass member had to be installed to account for full rupture of fatigued members.
- A steel arch bridge retrofitted in 1996 had a diagonal member broken after earthquakes.
- A retrofit for a Gerber hinge (i.e., in-span hinge) in a concrete bridge, added in 1997-1998, experienced failure in 2010, potentially due to corroding PC rods

The presentation raises critical questions about incorporating durability requirements into design specifications for seismic retrofit. The presented case studies emphasized the need for robust standards to ensure long-term safety and performance of retrofitted bridges, noting a lack of current standards for durability design in seismic retrofitting.

3.3.3 Open Discussion

The open discussion addressed key issues related to the durability and design of seismically retrofitted bridges. Participants discussed the challenges of using certain retrofit measures, including:

- Restrainers: it was noted that the crossed restrainers used by WSDOT may be easy to analyze, but they may create maintenance difficulties, and their effectiveness isn't always fully tested. Some alternatives, like high-strength rods, can damage girders, and springs used to accommodate thermal effects can gather dirt. WSDOT also noted that Washington used to install shear keys next to some girders in one span, but now WSDOT use shear kays among all girders.
- Fatigue life in retrofitted bridge: WSDOT currently doesn't consider live load in the pushover analysis in their seismic retrofit guides, but revisions to change this are underway. The discussion revealed that consideration of existing fatigue damage, although implemented in some signature bridges, can be challenging to be included for all bridges due to high uncertainties in the input variables.
- Durability of jackets: concrete jackets are susceptible to cracking from thermal and shrinkage effects. Stainless steel reinforcement is considered in Japan, but it lacks clear yielding behavior, causing ductility concerns. It may also accelerate corrosion if it touches existing reinforcing steel. FRP jacketing is commonly used in Japan, and its durability is considered generally good.
- Isolation: Japanese engineers noted a preference for rubber bearings over friction pendulum bearings because their testing methods are more established, which simplifies quality control and ensures durability. Friction pendulum bearings are more commonly used in places like Alaska and Hokkaido due to low temperatures. Tohoku EQ found more lead rubber bearing failure than expected: unbalanced structural stiffness may be the cause.

3.4 TOPIC 2D: POST-EVENT MANAGEMENT

Topic 2D included two presentations from the U.S. delegation and one presentation from the Japan delegation, followed by an open discussion. Presentation slides can be found in Appendix D.

3.4.1 Post-Event Response — Nick Murray (Alaska DOT&PF)

The presentation focused on emergency response and recovery following extreme events, with a primary emphasis on earthquakes, yet applicable to other hazards. It covered how agencies assess damage, the different levels of inspection, and the challenges they face in deploying resources and personnel. The presentation also introduced new technologies and strategies, such as AI-powered damage assessment and the use of temporary bridges, to improve response efforts. The main topics covered were:

- Post-event inspection: Many agencies utilize automated systems like ShakeCast to quickly estimate damage, which helps in prioritizing inspections. Information from social and traditional media can also be used, though with caution, to gather information about the extent of damage.
- Levels of inspection: The presentation outlined a tiered inspection approach, from informal observations by non-DOT staff to detailed inspections by qualified bridge inspectors. A key lesson learned is that formal documentation is often lacking during the initial, informal inspections. Marking needs to adjust for local conditions, and physical marking is simple and effective from Alaska's experience.
- Inspection guidance and training: New technologies like satellite images and AI are being explored to help non-technical staff assess structures remotely. The presentation highlighted the challenge of keeping inspectors trained for infrequent events and suggested less extreme events for drills and exercises.
- Temporary solutions: Agencies maintain an inventory of temporary bridges and repair materials for quick deployment after a disaster. One of the lessons learned is that these "temporary" solutions can sometimes become "permanent", depleting recovery resources upon future events.

3.4.2 Recovery Technology: Brace2 — Chris Traina (Caltrans)

The presentation offered an overview of BRACE2, a collaborative project between Caltrans and the University of California, Berkeley. The project aims to enable rapid post-earthquake bridge assessments, minimize transportation downtime, and help Caltrans make data-informed decisions. Key components of BRACE2 discussed in the presentation include:

- Core technologies: The system is built on digital twins, machine learning (ML), structural health monitoring (SHM), and real-time data streaming with digital twins.
- Prediction tools: There are two types of fragility models: Type I, which is detailed and based on physics and engineering rules, and Type II, which is faster and uses AI and data to predict behavior.
- Evaluation system: This system uses data to assess damage after an earthquake and impact to transportation functionalities, such as accessibility to hospitals and emergency services, and maintaining corridor performance

- Future development: The plan is to expand this tool to more areas, including Los Angeles and Sacramento, to help stakeholders make consistent and informed decisions.

3.4.3 Post-Event Management in Japan — Masahiro Shirato (NILIM)

Japan's high population density influences their approach to post-event management, which is different from the State DOT's responsibilities after events. In Japan, MLIT is tasked with delivering supplies to communities, with regional offices operating autonomously after major earthquakes. The system allows flexibility in emergencies, such as enabling work to begin without an immediate contract. MLIT has a team of specialized engineers called TEC-FORCE (Technical Emergency Control Force) who are trained as first responders. This is a notable feature of the Japanese post-event management. While Japan is starting to adopt new technologies, existing systems and protocols have proven to be reliable. Temporary bridge preparation and deployment were also discussed.

3.4.4 Open Discussion

During the open discussion, participants discussed new technologies and strategies for post-event management of bridges. It was noted that California's Strong Motion Instrumentation Program (CSMIP) has instrumented 85 bridges and, when used in combination with BRACE2, can supplement the ShakeCast system to pinpoint specific needs after an event. Using drones has significantly increased inspection efficiency and accessibility.

3.5 TOPIC 2E: NEW TECHNOLOGY & KNOWLEDGE UPDATE

Topic 2E included one presentation from the Japan delegation and two presentations from the U.S. delegation, followed by an open discussion. Presentation slides can be found in Appendix D.

3.5.1 Seismic Retrofit with Damping Devices — Michio Osumi (PWRI)

This presentation discussed seismic retrofitting of bridges using damping devices, highlighting current challenges and proposed solutions. It covered the ineffectiveness of some past damper applications and introduced various types of dampers. The presentation also addressed critical design considerations, modeling complexities, and validation methods for incorporating these devices effectively. Key points include:

- Past earthquakes showed unexpected damage at damper attachment points.
- Accurate 3D modeling is crucial for understanding bridge behavior with dampers.
- Quality control, fabrication, and maintenance are critical aspects for damper performance.

Overall, the presentation underscored the need for standardized design methodologies, improved modeling techniques, and rigorous quality control for the successful implementation of seismic dampers in bridge retrofitting. Experiments are ongoing to refine understanding of damper performance and impact effects.

3.5.2 New Technology and Knowledge Update — Nick Murray (Alaska DOT&PF)

This presentation focused on advancements and discussions concerning the seismic retrofit of bridges and structures. It covered emerging technologies, the impact of new seismological knowledge, and challenges in public perception regarding earthquake-resistant infrastructure. The presentation also highlighted ongoing research projects and the role of new technologies, such as drones in monitoring and improving seismic resilience. Key messages from the presentation include:

- Re-screening procedures for seismic hazards are important due to new knowledge.
- Geotechnical failures are a primary cause of road closures after earthquakes.
- Research is underway on advanced materials and resilient structural members.
- Drones are being deployed for avalanche monitoring and control near highways.
- Public expectations about earthquake damage to modern bridges need to be managed.
- New developments include ductile high strength reinforcing steel and plastic hinge relocation.

3.5.3 Seismic Performance of Geotechnical Elements — Khalid Mohamed (FHWA)

This presentation examined the seismic performance of various geotechnical elements. It focused on post-event observations to assess the effectiveness of current designs and identify areas for improvement in earth retaining structures, natural and manmade slopes, embankments, and liquefaction assessment. New findings and suggested changes for liquefaction potential assessment were also explored.

3.5.4 Open Discussion

Discussion highlighted several key areas of concern regarding new technology, knowledge updates, and seismic retrofitting. The Japan delegation noted the need for national standards for dampers, as current practices do not typically account for three dimensional movement, and different suppliers have their own testing protocols.

Another major theme was the performance of geotechnical elements during seismic events. Specifically, unreinforced embankments and liquefaction are some of the major concerns. Inertial forces are a critical consideration in liquefaction analysis. There is a need to reduce uncertainty in liquefaction models, possibly by accounting for factors like spatial correlation and changes in ground water levels. Given the high cost of ground improvement, the importance of site-specific knowledge and accounting for site variability was emphasized as a key direction for future work. Geotechtools.org provides some useful information.

The presentations also covered the challenges of communicating with the public and stakeholders about seismic performance. There's a misconception that retrofitted bridges should be "earthquake-proof". It's crucial to convey that some visible damage is expected and may even be a desired outcome that balances risk and cost. The discussion also brought up the holistic consideration of system performance and impacts to different stakeholders when deciding on retrofitting actions. The FHWA NextScour Project was recommended as an example of a more holistic approach.

3.6 TOPIC 2F: RESEARCH NEEDS/ROADMAP

3.6.1 Day 2 Summary

The session summarized discussion under each subtopic of Topic 2. The session was led by Jerry Shen (FHWA). The summary, as prepared by Tom Murphy (Modjeski and Masters), was provided in Appendix D.

3.6.2 Open Discussion

Research and roadmaps were discussed and summarized as follows:

- Seismic design needs to advance as the times have changed, in particular with relation to Nonlinear Time History Analysis. Questions remain about how to and whether to use NLTHA for retrofit design, e.g., setting resistance and load factors and how these interact with the design intent regarding the load path.
- Element and material technology should be further developed, e.g., use of highly durable materials like stainless steel; the seismic performance of the entire bridge in relation to its component performance should be better understood.
- Pace of engineering development has decreased; it has been many years since the last major seismic events in the U.S.
- Understanding is needed regarding how the increased performance of one member will affect other members and the overall structure. Assumed versus actual behavior, and how the retrofit interacts with daily traffic loading.
- Life cycle concepts are needed in the development of seismic retrofit designs and strategies.
- Seismic retrofit is not a topic of education in universities (focus has traditionally been on the design of new bridges).
- Both countries are working on developing or updating specifications for the seismic retrofit of bridges.
- Good seismic detailing (confinement, shear capacity, ductility) has benefits for other hazards and loadings. Promoting robust detailing that can help seismic and live loads. Coordinating needs, especially conditions and retrofitting, can align different actions and optimize the use of available retrofit funds. Seismic retrofit should be incorporated into the total asset management plan for bridges and networks.
- Evaluation methods for the performance of restrainers, consideration of impact loads.
- Consideration of deterioration over time, and how that affects a retrofit design; service life of retrofit elements; the concept of load rating for seismic hazards (through fragility functions).
- Other parts of the built environment have much to teach us, for instance on the use of dampers.
- Addressing post-earthquake damage considering aftershocks.
- For curved and complex geometries of bridges, common rules for determining axes of analysis (longitudinal and transverse for these situations.)
- Quick repair after EQ for emergency response
- Need for resilience-oriented detail design

CHAPTER 4

SITE VISITS

4.1 FISHING WARS MEMORIAL BRIDGE: BRIDGE INSPECTION EXERCISE

Fishing Wars Memorial Bridge serves as an important bypass route within Tacoma's freight network. The current structure is a 1920-era steel truss structure owned by the City of Tacoma. At the beginning of the site visit, the city engineers and officials provided a brief overview of the history and the present status of the bridge. Currently, the bridge is closed to traffic due to pending cleaning and inspection. It is also subject to load restrictions because the structure was not designed for today's commercial truck traffic. The delegations were given a guided tour through the bridge truss and informed about the dirt and debris accumulation and environmental considerations that have complicated the effort to clean the bridge to allow inspection of the bottom chord and truss member connections.

Source: FHWA

Figure 4.1. Photograph. Fishing Wars Memorial Bridge (east approach)

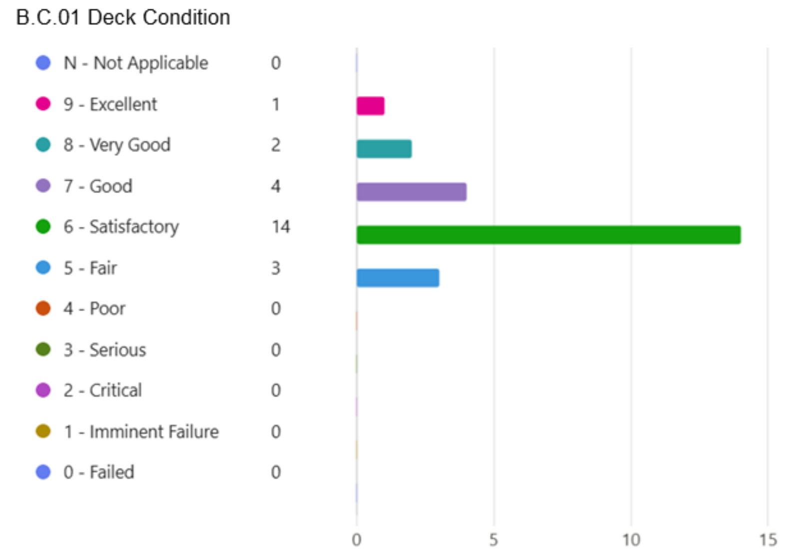
To better understand the features of the inspection data collection standards in the U.S. and Japan, the site visit featured a bridge inspection exercise on the 8 concrete beam spans of the east approach to the truss, as shown in Figure 4.1. Delegations from both countries were asked to evaluate the bridge and the bridge elements using both the U.S. and the Japanese inspection standards, i.e., the Specifications for the National Bridge Inventory (FHWA, 2022) and Bridge Inspection Manual (MLIT, 2004), respectively. Spans are numbered west to east. Each span has 5 girders, labeled 1 to 5, from south to north. The inspection exercise included the evaluation of the following:

- Deck, superstructure, substructure General Condition Ratings (GCRs) and bridge condition classification, evaluated based on the U.S. inspection standard (ref)

- Condition ratings of bridge railing, railing transition, bridge bearings, and bridge joints, evaluated based on the U.S. inspection standard
- Load posting status, evaluated based on the U.S. standard
- Integrity diagnosis classification, evaluated based on the Japanese standard (ref)
- Cracking classification, crack pattern, and exposed rebar classification of three segments in Span 5, evaluated based on the Japanese standard
- Condition state of the same three segments with respect to delamination/spalling, exposed rebar, and cracking, evaluated based on the U.S. inspection standard

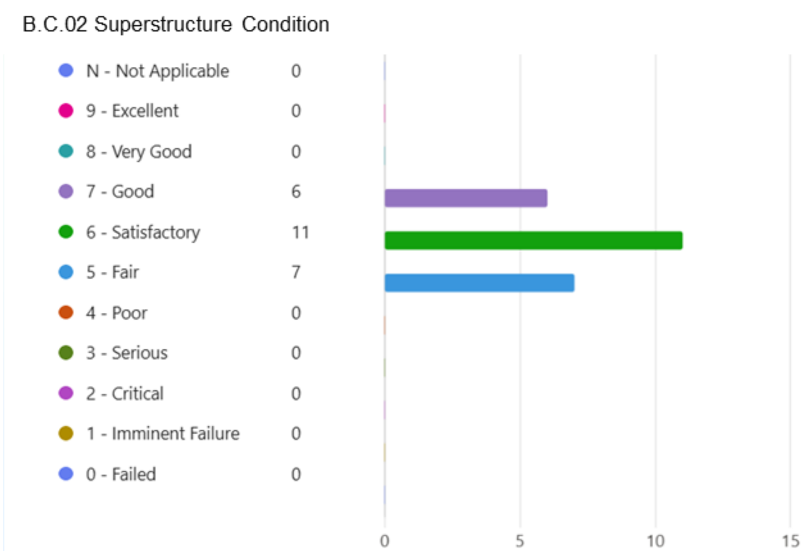
Prior to the site visit, reference charts, excerpted from the standards and included in Appendix E, were provided to the delegations to facilitate the inspection exercise. All inspection questions and distributions of responses are summarized in Figure 4.2 to Figure 4.16. The inspection exercise was then followed by a debriefing meeting, where the results were discussed. Key discussion points are summarized as follows:

- Deck, super, and substructure GCRs have a clear majority, with superstructure GCR gaining the most consensus
- Bridge railing GCR has high variability among participants
- Due to a lack of bearings in the inspected spans, a majority of participants coded "N" for "not applicable", while several participants rated the "bearing region" instead of coding "N". It was noted that both could be acceptable, but clear documentation and consistency with historical records should be maintained.
- Unlike the bridge condition classification in the U.S., the Japanese overall integrity diagnosis classification is more related to actions needed instead of focusing solely on conditions. For instance, "3" may be coded if actions are needed to mitigate impacts on third parties (e.g., pedestrians underneath bridges) even though the structure itself is in a fair condition. These third-party impacts do not seem to be explicitly considered in the U.S. standards, though they may appear in inspectors' notes.
- There were debates on crack pattern classification. It was noted that only excerpts from the Japanese standards were provided in this exercise. The diverse example pictures of crack patterns in the full document can be very helpful to avoid inconsistencies in element inspection results
- Condition state results show clear consensus on ratings CS1/CS2 over ratings CS3/CS4. More definite distinctions between CS1 and CS2 may be needed.



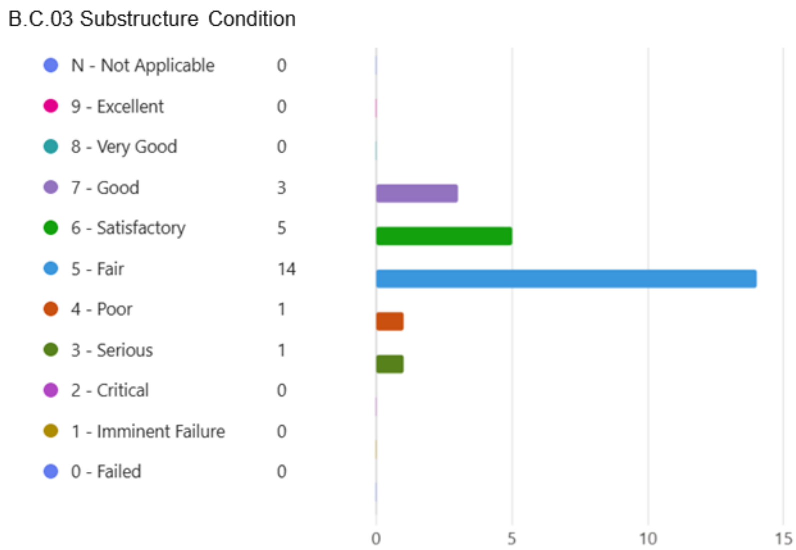
Source: FHWA

Figure 4.2. Graph. Responses for deck condition rating.



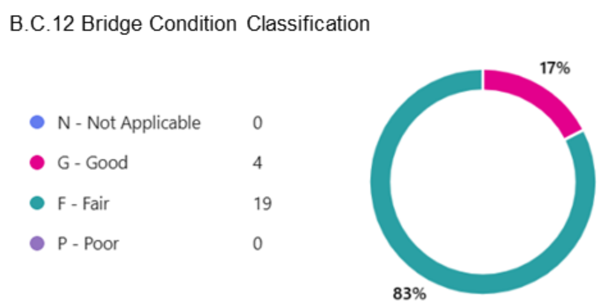
Source: FHWA

Figure 4.3. Graph. Responses for superstructure condition rating.



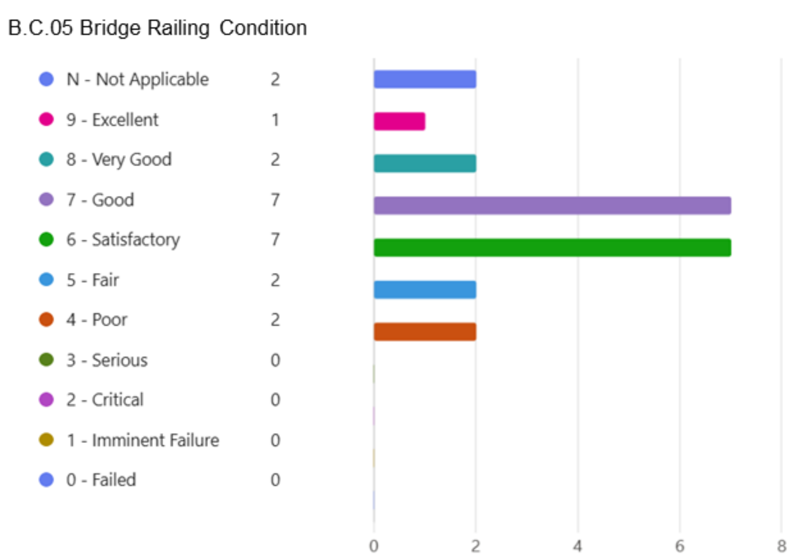
Source: FHWA

Figure 4.4. Graph. Responses for substructure condition rating.



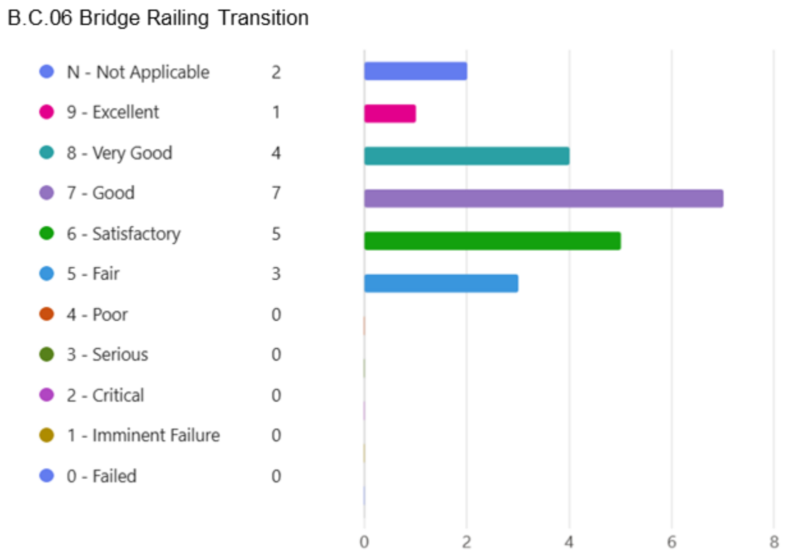
Source: FHWA

Figure 4.5. Graph. Responses for bridge condition classification.



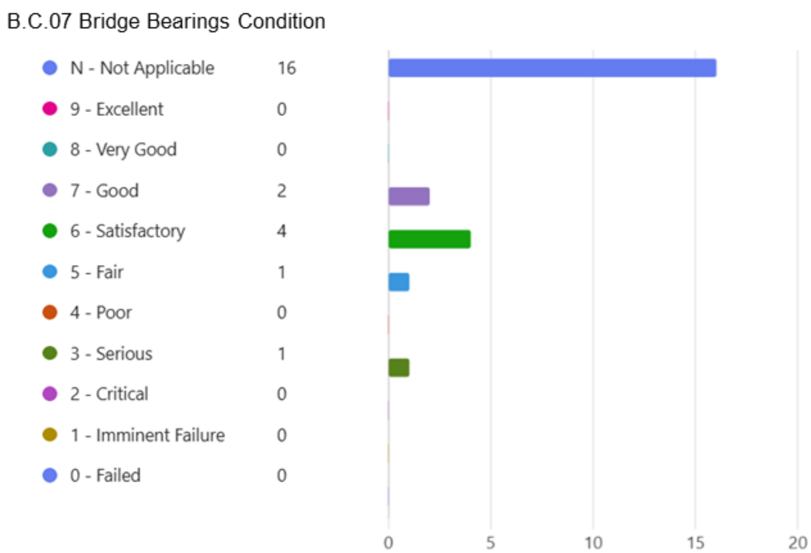
Source: FHWA

Figure 4.6. Graph. Responses for bridge railing condition rating.



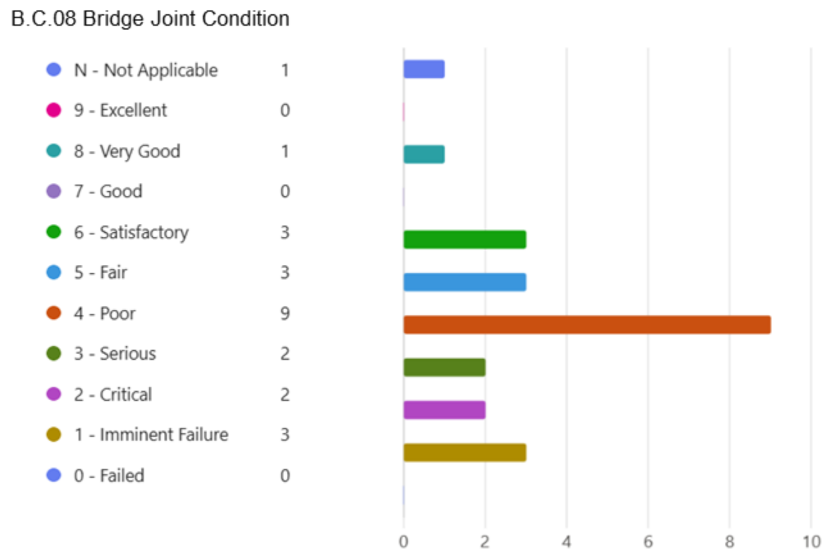
Source: FHWA

Figure 4.7. Graph. Responses for bridge railing transition condition rating.



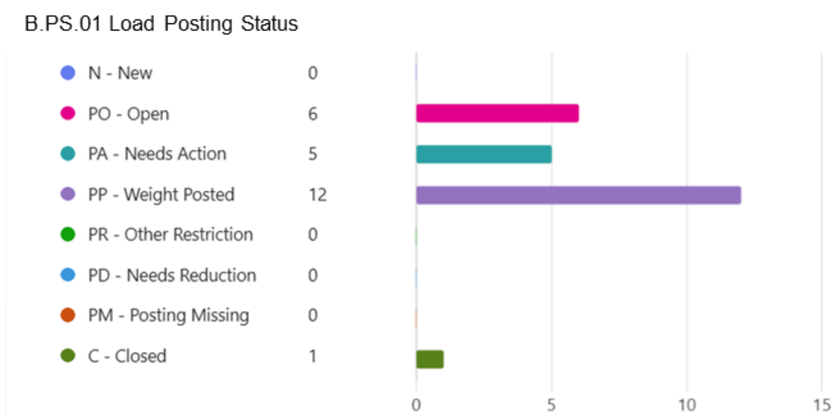
Source: FHWA

Figure 4.8. Graph. Responses for bridge bearing condition rating.



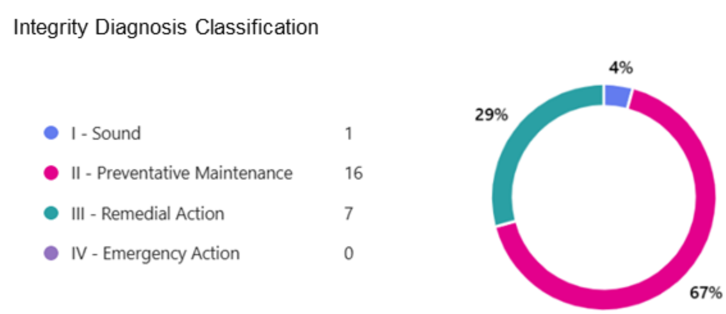
Source: FHWA

Figure 4.9. Graph. Responses for bridge joint condition rating.



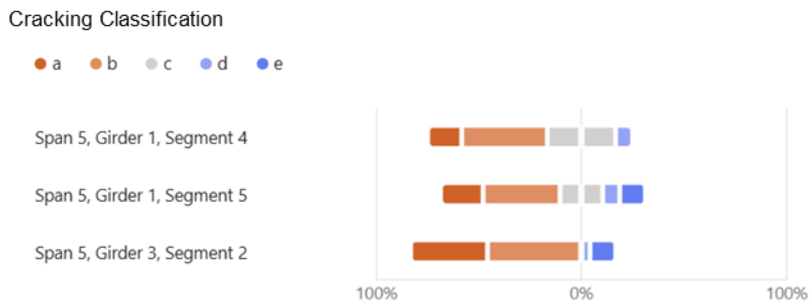
Source: FHWA

Figure 4.10. Graph. Responses for load posting status.



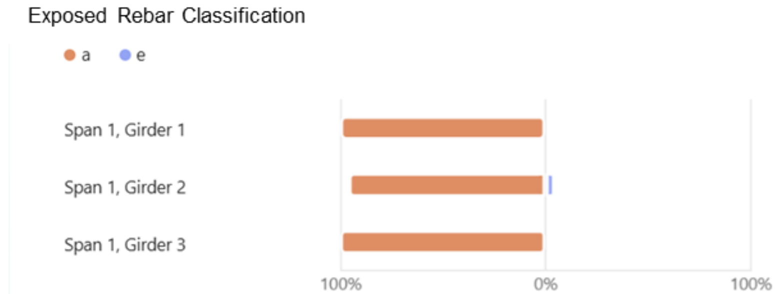
Source: FHWA

Figure 4.11. Graph. Responses for integrity diagnosis classification.



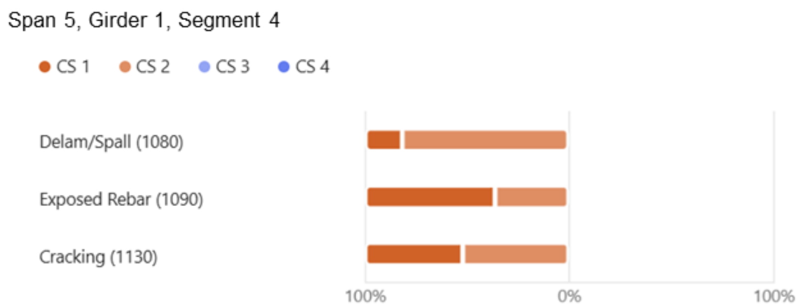
Source: FHWA

Figure 4.12. Graph. Responses for cracking classification.



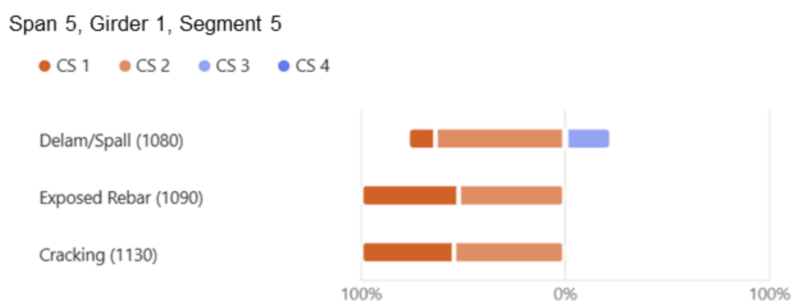
Source: FHWA

Figure 4.13. Graph. Responses for exposed rebar classification.



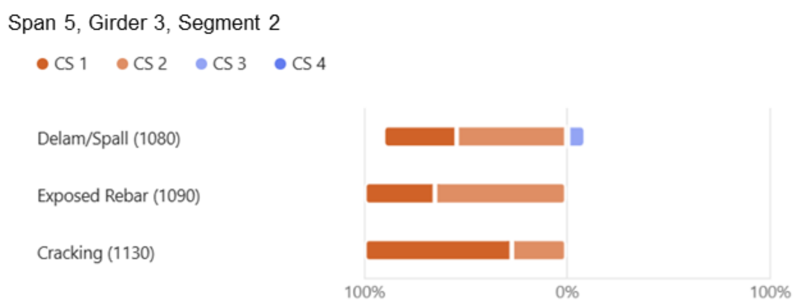
Source: FHWA

Figure 4.14. Graph. Responses for condition state (Span 5, Girder 1, Segment 4).



Source: FHWA

Figure 4.15. Graph. Responses for condition state (Span 5, Girder 1, Segment 5).



Source: FHWA

Figure 4.16. Graph. Responses for condition state (Span 5, Girder 3, Segment 2).

The inspection exercise was organized by Stephen Bartha (FHWA) and Derek Soden (FHWA) in coordination with the WSDOT and the City of Tacoma. Stephen hosted the debriefing session and discussion afterwards.

4.2 PUGET SOUND GATEWAY PROJECT

The second site visit was to the Puget Sound Gateway project that is currently under construction. Prior to the visit, Tom Slimak, Project Engineer from WSDOT, provided an overview of the project, including wetland restoration, multi-use trails and transit, diverging diamond interchanges, and tolling expressway.

4.3 SR520 FLOATING BRIDGE

As of August 2025, the SR520 Bridge completed in summer 2017 is one of the world's longest floating bridges. It serves as a vital link between Seattle and the growing cities east of Lake Washington. The tour specifically featured the technologies and innovations, as well as the operation and maintenance, related to its pontoon structure. The site visit was arranged and organized by Evan Grimm (WSDOT) in coordination with other WSDOT staff.

4.4 SR99 (ALASKAN WAY) TUNNEL

The SR99 Tunnel, also known as the Alaskan Way Viaduct replacement tunnel, is a bored highway tunnel in the city of Seattle. The tunnel runs two miles beneath downtown Seattle and deploys various technologies and innovative solutions to its construction, daily operation, and emergency response. The tour primarily featured the traffic monitoring system, emergency response protocols, and power and electrical systems. The site visit was arranged and organized by Evan Grimm (WSDOT) in coordination with other WSDOT staff.

CHAPTER 5

SUMMARY AND FUTURE COLLABORATION

In both the U.S. and Japan, bridge ownership and asset management responsibility are spread across national, state/prefecture, and local agencies and authorities. Consistent inspection practice and results across these agencies is an important consideration in the implementation of national-level programs in both countries. The discussion in this Workshop and comparative inspection exercise provided a unique opportunity to develop deep understanding for the different practices and to experience features of each inspection method in the field as well as identify areas prone to variable interpretations.

U.S. bridge owners have, over the last several decades, been implementing refinements to the collection and use of bridge inspection data to better support performance-based asset management systems used for forecasting needs and analyzing alternative investment strategies and work programs. While bridge inspection and management are not new to Japanese bridge owners, national-level inspection and asset management requirements in Japan are a more recent development. Both countries are interested in further developing the use of asset management principles and systems to leverage data collected during bridge inspections, to coordinate preservation, maintenance, and retrofitting efforts, and to optimize bridge-, corridor-, and network level performance. This would also extend to an interest in risk-assessment procedures including corridor-level risk assessment that includes risk of damage from extreme events to both structural and geotechnical assets.

Since the 1990s, bridge owners in both countries have carried out bridge seismic retrofitting projects. There is a common need for updating the goals and guidance for retrofit programs among bridge owners. Reasons include:

1. Initial retrofit programs were intended for an urgency of reducing catastrophic collapse for pre-seismic design bridges.
2. A systematic and performance-based programing approach is preferred. Performance targets may have evolved with the changes in social and economic demands.
3. After in service for several decades, more knowledge on seismic performance and durability of retrofit strategies, approaches, and measures can be applied to future retrofit programs.
4. There is a demand on better integration with consideration of non-seismic design aspects.

Extending the evaluation and retrofitting efforts to other hazards such as flooding and coastal storms is also among the common interest. Developing programs that support these efforts is a potential collaboration topic. Further technical exchange will increase the knowledge base for developing future retrofit guidance and programs in the U.S. and Japan.

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MLIT, 2004. Bridge Inspection Manual. Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Tokyo, Japan.

APPENDIX A WORKSHOP PARTICIPANTS

U.S. DELEGATION

Gina Ahlstrom, Acting Director, Office of International Programs

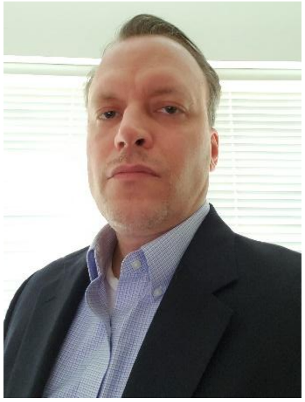
Gina Ahlstrom began serving as the Acting Office Director for the Office of International Programs in February 2025. Gina joined the Office of Policy and Governmental Affairs in 2025 as the Office of International Programs Resource Management Team Leader. Gina's interest and passion for international programs started when she was appointed as FHWA's technical expert to the World Road Association's (PIARC) Technical Committee on Pavements in 2015. Gina has held PIARC leadership roles of Working Group Leader and English-speaking Secretary. Prior to joining the Office of International Programs, Gina served as the Pavement Materials Team Leader in the Office of Preconstruction, Construction, and Pavements. Gina joined FHWA in 2005 as a pavement engineer. She created and led several large projects and major programs during her time in the Office of Infrastructure. For much of her career, she worked in the technical area of asphalt and concrete pavement materials and pavement design and analysis. At the forefront of these programs was technology deployment and addressing the needs of stakeholders such as State DOTs, industry, and academia. Her motivation for stakeholder engagement came from her time working at the Maryland State Highway Administration from 2000-2005. During her time in Maryland, she worked as a pavement designer and spent six months as a construction inspector. Gina has a Bachelor of Science degree in Civil Engineering from the Pennsylvania State University and a Master of Science degree in Civil Engineering from the University of Maryland.

Harjit Singh Bal, P.E. is a registered Professional Engineer working in the capacity of Supervising Engineer in the NJDOT Bureau of Structural Evaluation & Bridge Management overseeing the Bridge Management Systems, Bridge Resource Program, Bridge Inspection, and Bridge Asset Management. As a part of the Asset Management Team, Harjit is responsible for supporting New Jersey's Transportation Asset Management Plan for bridge assets. He is actively involved in the AASHTOWare's Bridge Management User Group Meeting which primarily focuses on the development of BMS tools for Deterioration and Predictive Modeling, Multi-Objective Optimization, Lifecycle Planning, Projects Prioritization, and Risk Assessment Management. His experience includes more than 20 years in Structural Evaluation, Bridge Management, and Geotechnical Engineering Design. To his credentials, Harjit graduated with a Bachelor of Engineering degree in Civil Engineering from India, a second Bachelor of Science degree in Computer Science from Rutgers University, a Master of Science degree in Transportation Engineering from NJIT, and Master of Business Administration from Thomas Edison State University.

Stephen Bartha is the Senior Tunnel Safety Engineer on the Safety Inspection Team with the Federal Highway Administration's Headquarters Office. He has over 20 years of experience in the inspection, rating and management of bridges and tunnels. Mr. Bartha's responsibilities include maintaining the National Tunnel Inspection Program in addition to the FHWA's oversight reviews of the bridge & inspection programs. Stephen is currently serving as the Acting Team Leader for the Safety Inspection Team in addition to his regular responsibilities.

Ian Buckle is Foundation Professor Emeritus in the Department of Civil and Environmental Engineering at the University of Nevada Reno. His research interests include improving the seismic performance of highway bridges, design and retrofit criteria for bridges, earthquake protective systems, tsunami loads, and soil-structure-interaction for buried bridges. His most recent contributions to AASHTO's specifications include work on performance-based seismic design, risk-targeted ground motions, and tsunami design loads for bridges.

Derek Constable is a Bridge Management Engineer with Federal Highway Administration's Office of Bridges and Structures. He serves as the primary representative on the management of bridges and structures. Derek contributes to local and national programs, research, technology deployment, and training initiatives and provides direction for systematically managing structural assets efficiently and cost-effectively. Derek has also served in bridge positions with FHWA Pennsylvania Division, FHWA Maryland Division, Federal Lands Highway office, and New York State DOT.



Andrew Fiske has nearly 20 years of experience with the Washington State Department of Transportation (WSDOT), where he currently serves as the State Geotechnical Engineer. His career spans coast-to-coast and encompasses expertise in civil design, construction oversight, and geotechnical engineering in both public and private sectors. Andrew champions the development of best practices within the geotechnical profession and is dedicated to mentoring and fostering the next generation of geo-professionals. He contributes to the advancement of the field as a member of the Soil Structures and Seismic subcommittees of the AASHTO Committee on Bridges and Structures and serves as a DOT representative on several national research projects. Additionally, Andrew is a member of the Community Advisory Board for the Civil Engineering program at the University of Washington Tacoma.

Evan Grimm is the State Bridge & Structures Engineer at the Washington State Department of Transportation. With experience in both the private and public sectors, his background includes structural design of bridges and waterfront structures with traditional and alternative delivery methods.

Erich Hart: I am a bridge asset engineer for the Indiana Department of Transportation (INDOT) central office. I have been with INDOT for 6 years. The 20 years prior to that, I did bridge design for INDOT as a consultant. One of my primary roles for INDOT Bridge Asset Department is running and maintaining our bridge forecasting model.

Amy Leland is the State Bridge Design Engineering for Washington State DOT, where she has worked since 1999. Amy earned her Masters of Science in Engineering degree from the University of Washington, and is licensed as a Professional Engineer and a Structural Engineer. She has many years of bridge design experience and has participated in establishing policy and overseeing research for WSDOT.

Ed Lutgen has a bachelor civil engineering degree from the University of Minnesota in 1995. He is a registered engineer in Minnesota. He has 30 years of bridge experience with positions in inspection, load rating, construction, design, preliminary, geotechnical, and operations. Currently he is the State Bridge Engineer for Minnesota responsible for over 20,000 bridges and manages an office of approximately 140 engineers and technicians.

M. Lee Marsh, Ph.D., P.E. is a Senior Vice President and Technical Fellow in Earthquake Engineering for WSP USA, Inc. His practice has involved research for bridge seismic performance, development and maintenance of industry design specifications, and seismic design of numerous bridges and marine structures. He has taught NHI courses on the seismic design of bridges since 1996, and he is a nationally recognized expert in the seismic design of bridges.

Philip Meinel is a Structures Asset Management Engineer for the Wisconsin Department of Transportation. He has 13 years experience with bridge design, inspection, maintenance, and network-level asset management systems. He is primarily responsible for developing bridge management software to predict future bridge work. He also leads the collection and utilization of non-destructive evaluations on bridge decks throughout the state. He is currently serving as vice-chair of the Midwest Bridge Preservation Partnership, and is chair of the national working group on bridge management systems.

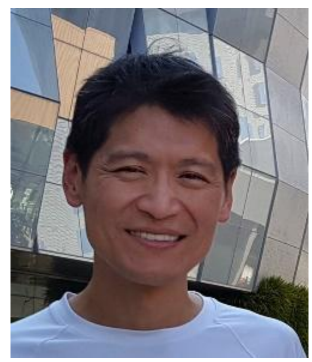
Khalid Mohamed, P.E., PMP, Senior Geotechnical Engineer
Mr. Khalid Mohamed is a Senior Geotechnical Engineer with the Federal Highway Administration in the Office of Bridges and Structures. He has over 24 years of federal service, leading teams to support geotechnical and transportation initiatives, research, and programs. Given his geotechnical expertise, he supports FHWA initiatives in the areas of safety, cost-effectiveness, congestion mitigation, geohazard event response, and climate change resilience. He also led teams in performing geotechnical engineering design and construction management for small and large complex highways and bridge projects within Federal Lands parks, forest services, wildlife refuges, and other locations. He currently leads the FHWA Geohazards, Extreme Weather Events, and Resilience Program. Before joining FHWA, Khalid worked for 10 years in the private sector and academia, where he was involved in the design and construction of various infrastructure projects. Mr. Mohamed holds a master's degree in Civil (Geo-environmental) Engineering from Howard University, holds his Professional Engineer license in the District of Columbia, and has his Project Manager Professional (PMP) certification.

Thomas Murphy: Dr. Murphy is a Senior Vice President and the Chief Technical Officer at Modjeski and Masters, Inc. He holds a Ph.D. in civil engineering from the University of Michigan and is a registered Professional Engineer in more than 30 States. His professional experience encompasses the analysis, design, detailing, and rehabilitation of a variety of bridges including cable-stayed, suspension, arch, truss, and girder bridges with special emphasis on seismic analysis and design as well as design specification development and research. He has led and/or participated in 10 NCHRP projects.

Nicholas Murray is a Senior Bridge Engineer with the Alaska Department of Transportation & Public Facilities and serves as vice-chair of AASHTO's Seismic Design Subcommittee within the Committee on Bridges and Structures. He leads bridge design and retrofit efforts in Alaska with a focus on seismic resilience, research implementation, and emergency response planning.

Lori Porreca, Acting Team Lead/International Program Manager, Office of Policy/Office of International Programs
Lori Porreca began as Acting Team Lead for the Office of Policy Administrative and Finance Team in April 2025. Prior to this Lori has been an International Program Manager with the Federal Highway Administration (FHWA) since 2019. She manages bilateral relationships for the Office of International Programs and represents the agency on several World Road Association committees. Prior to this, she served as a Community Planner for the FHWA Idaho Division Office for 10 years. She has 20 years of experience in Planning and Transportation. She holds a PhD in Sociology, a master's degree in landscape architecture and environmental planning and a bachelor's degree in English Literature and Philosophy and is a certified planner with the American Institute of Certified Planners.

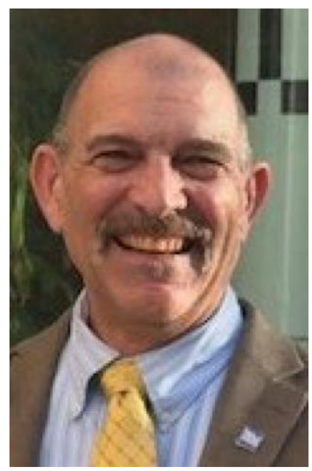
Jia-Dzwan (Jerry) Shen: Jerry is the seismic specialist at the Office of Bridges and Structures, FHWA. He is responsible for managing the Seismic and Multi-Hazard Resilience Program, which coordinates the development and deployment of effective engineering practice against earthquakes and other natural threats to highway structures. He is a liaison to the AASHTO Seismic Technical Committee. His past experience encompasses seismic, wind, and hydraulic engineering relevant to bridges.



Derek Soden, P.E., S.E. – Derek leads the Structural Engineering Team in the Federal Highway Administration's Office of Bridges and Structures and is FHWA's Principal Structural Engineer. In this role, Derek is responsible for planning and managing national level programs targeted at improving the state of practice of structural engineering as applied to the planning, selection of type, size and location, design, construction, and evaluation of highway bridges and structures. He leads a staff of highly qualified engineers that provide technical leadership and guidance to State DOTs, industry, and other FHWA offices.

From 2012 to 2020, Derek was a Senior Structural Engineer with the FHWA Resource Center, where he provided technical assistance and training in the areas of bridge design, construction, inspection, and evaluation. Prior to that, from 2009 to 2012, Derek was the Assistant Division Bridge Engineer for FHWA's Florida and Puerto Rico Divisions. Before joining FHWA, from 1998 to 2009, Derek was a bridge design engineer for the Alaska Department of Transportation and Public Facilities where he developed designs for new bridges and bridge repair, rehabilitation, and seismic retrofit projects throughout the state.

Chris Traina: Chris graduated with a BS in Civil Engineering from New Mexico State University in 1986 and served as an Engineer Officer with the United States Army from 1986 to 1991.



Chris joined Caltrans in May of 1991 and worked on seismic retrofit projects in the Phase 1 and Phase 2 Seismic Retrofit Programs, and the Toll Bridge Program from 1991 to 2014. He managed three demolition contracts between 2014 and 2018 that resulted in the successful removal of eighteen marine foundations from the San Francisco Bay. Chris currently manages the Office of Earthquake Engineering, Analysis, and Research in the Division of Engineering Services.

Loren Wilson, P.E. – Born and raised in Washington State, Loren received his B.S. in Civil Engineering from Washington State University in 2007 before starting as a structural inspector with WSDOT in their Special Structures unit, focusing on larger complex structures throughout Washington, including performing Underwater inspections as part of the WSDOT Dive Team. In 2021 joined FHWA as the Washington Division Bridge Engineer and is currently performing NBIS and NTIS oversight in Washington, Oregon and Alaska.

David Y. Yang, Ph.D., is an Assistant Professor of Structural Engineering in the Department of Civil and Environmental Engineering at Portland State University, Oregon. His research focuses on risk-based asset management of infrastructure systems, with a particular emphasis on deterioration, catastrophic events, and system performance. He is the author of 34 journal articles, 6 peer-reviewed book chapters, and over 15 papers in conference proceedings.

Tony Yoon has over 25 years of experience in projects encompassing various aspects of structural, geotechnical, and earthquake engineering. As a Senior Bridge Engineer at Caltrans Office of Earthquake Engineering, he focuses on the seismic design and analysis of complex bridges. His work includes supporting bridge engineers on various design projects. In addition, he currently serves as a chair of Caltrans Tunnel committee. He got his bachelor's degree in civil engineering at Chung Ang University, South Korea and obtained a master's degree in civil engineering at Texas A&M University.

JAPAN DELEGATION

Name: SHIRATO Masahiro
Affiliation: National Institute for land Infrastructure Management
Dr. Shirato is Head of Bridge and Structures Division, at NILIM, MLIT, Japan. He leads MLIT research projects to develop technical policies, codes, and guidelines for road bridge design, inspection, preservation, and rehabilitation. He also has academic publications in bridge engineering and geotechnical engineering.

Name: **MIYASHITA Takeshi**
Affiliation: **Nagoya Institute of Technology**
Professor Takeshi Miyashita at Nagoya Institute of Technology specializes in structural health monitoring and strengthening of steel structures, particularly bridges. His recent work focuses on applying carbon fiber-reinforced polymer (CFRP) to reinforce aged or corroded steel-truss and steel-girder members using both experimental load tests and nonlinear finite-element modeling. He also advances non-destructive evaluation methods, such as piezo impedance sensing and laser Doppler vibrometry, to assess the integrity and vibration characteristics of bridge components. His interdisciplinary approach integrates analytical modeling, lab testing, and field monitoring to improve the safety and extend the service life of infrastructure.

Name: **NOZAKA Katsuyoshi**
Affiliation: Ritsumeikan University
Professor, Ph.D.
Department of Civil and Environmental Engineering College of Science and Engineering Ritsumeikan University.
Major and interest:

- Load carrying capacity of steel structures，such as shear strength of hybrid girders
- Strengthening and retrofitting considering use of both steel plate and fiber reinforced materials
- Inelastic design of steel girders, focusing on the moment redistribution in steel bridges having proportions in Japanese specification

Name: **ONO Kiyoshi**
Affiliation: Waseda University
Professor of Civil and Environmental Engineering, Waseda University.
I am conducting research on the development of seismic design methods for steel bridges, the development of load-bearing capacity evaluation methods, and the investigation of material properties of new materials and their application to steel bridges.

Name: **AKIYAMA Mitsuyoshi**
Affiliation: Waseda University

Dr. Mitsuyoshi Akiyama is a Professor at Waseda University, Japan, whose research focuses on the life-cycle performance assessment of infrastructure systems subjected to multiple hazards. He currently serves as Chair of the Committee on Reliability and Performance Indicators within the Structural Engineering Institute of ASCE, and as Chair of Commission 6 on Sustainability within IABSE. He is Managing Editor of Structure and Infrastructure Engineering, Associate Editor of the ASCE Journal of Bridge Engineering, and serves on the editorial boards of several international journals, including Structural Safety and Probabilistic Engineering Mechanics. Dr. Akiyama is also a member of the Executive Committees of both IABMAS and IALCCE, and serves on the Executive Board of IASSAR.

Name: **HANJI Takeshi**
Affiliation: Nagoya University

My primary research focuses on the fatigue, fracture, and maintenance of steel structures. I am working on the development of highly accurate fatigue strength prediction methods, techniques to improve fatigue strength, efficient repair and reinforcement strategies, and simple methods for detecting fatigue cracks.

In addition, I am conducting research on rational maintenance approaches using crack propagation simulations. I am also actively involved in building a database on fatigue damage and countermeasures, with the long-term goal of developing an AI-based crack diagnosis system.
Currently, I serve as Chair of Subcommission E "Maintenance of Welded Structures" under Commission XIII of the International Institute of Welding (IIW).

Name: **NAITO Hideki**
Affiliation: Tohoku University

Hideki Naito (Dept. of Civil and Environmental Engineering, Tohoku University): I am glad to participate in the nice workshop! My major is structural engineering, for example, seismic design and health monitoring for concrete structures. I am interested in measures for natural disasters with civil structures and maintenance of the structures in the U.S.

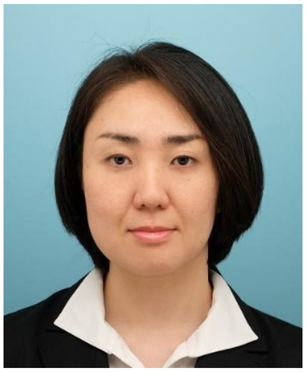
Name: **FUJIYAMA Chikako**
Affiliation: Yokohama National University
Chikako Fujiyama, Yokohama National University, Faculty of Urban Innovation, Department of Civil Engineering, Dr. Professor
After seven years as a bridge design consultant, I earned a Ph.D. in engineering. My experience covers bridge and substructure design, seismic retrofitting, and numerical evaluation of material degradation. My research interests include bridge decks, high-cycle loading, concrete fatigue in wet conditions, steel-concrete composites, and nonlinear analysis.

Name: **OHSUMI Michio (Dr.)**
Affiliation: Public Works Research Institute
Chief Researcher, Center for Advanced Engineering Structural Assessment and Research (CAESAR), National Research and Development Agency Public Works Research Institute (PWRI)
- Committee of bridge, Japan Road Association (JRA) (Secretary for Connection between Super-Sub structure)
- Subcommittee on Seismic Design for Bridges, Japan Society of Civil Engineers (JSCE) (Chairperson)

Name: **KOGA Hirohisa (Dr.)**
Affiliation: Public Works Research Institute
Hirohisa Koga is a Chief Researcher for Concrete and Metallic Materials of the Innovative Materials and Resources Research Center (iMaRRC) at the Public Works Research Institute (PWRI). He received his PhD from Kyoto University, Japan. His research interests include quality control of concrete works and durability of concrete structures.

Name: **NAKAMURA Eisuke (Dr.)**
Affiliation: Public Works Research Institute
Eisuke Nakamura is a Chief Researcher of the Center for Advanced Engineering Structural Assessment and Research (CAESAR) at the Public Works Research Institute (PWRI). He received his PhD and MSc from Tohoku University, Japan, and the University of Texas at Austin, TX, respectively. His research interests include the structural performance and durability of reinforced and prestressed concrete road bridges.

<u>Name:</u> HIROE Akiko
<u>Affiliation</u>: Public Works Research Institute
Akiko Hiroe is a senior Researcher of the Center for Advanced Engineering Structural Assessment and Research (CAESAR) at the Public Works Research Institute (PWRI). She received her MSc from Waseda University, Japan. Her research interests include the Seismic design and reinforcement of road bridges.



<u>Name:</u> NINOMIYA Tomohiro
<u>Affiliation</u>: Public Works Research Institute
Tomohiro Ninomiya is a senior Researcher of the Center for Advanced Engineering Structural Assessment and Research (CAESAR) at the Public Works Research Institute (PWRI). He received his MSc from Kyoto University, Japan. His research interests include the seismic reinforcement of road bridge foundations.

<u>Name:</u> KUWANO Jinsei
<u>Affiliation</u>: Public Works Research Institute
Jinsei Kuwano is a Researcher of the Center for Advanced Engineering Structural Assessment and Research (CAESAR) at the Public Works Research Institute (PWRI). He received his MSc from Tokyo institute of Technology, Japan. His research interests include the structural performance and durability of reinforced and prestressed concrete road bridges.

APPENDIX B PREWORKSHOP QUESTIONS

QUESTIONS FROM U.S. DELEGATION TO JAPAN DELEGATION

Topic 1-1: Bridge Inspection, Maintenance, and Post Inspection Actions

1. The U.S. delegation would like to hear more about segmental data collection, including how it might be used in asset management.
2. What new technologies is Japan using to collect, analyze, store, and report condition data (for example, AI tools to measure and report bridge defects)?
    a. What technologies and software are used to analyze and visualize bridge data?
3. Example technologies of interest to the U.S. delegation are Building Information Models (BIM) for inspection and management, geographic information systems, nondestructive evaluation, structural monitoring, artificial intelligence.
4. Are funds in Japan allocated for risk mitigation of bridges? What risk variables and data should be used for fund allocation and project selection decisions?
5. How might emerging technologies provide in terms of
    a. more meaningful data and analytics to help address the effectiveness of preservation and other actions,
    b. decision-making on optimal investment and actions,
    c. measuring changes in performance with limited history of data or after actions,
    d. assessing deterioration rates and drivers,
    e. separating load/force and environment induced deterioration, additional/refined bridge attribute information, etc.?

Topic 1-2: Structural Evaluation and Repair and Retrofit Decisions

1. Are there any standard structural evaluations made for in-service bridges in Japan (such as current live load capacity)?
2. Are any data commonly collected regarding the results of structural evaluations made for in-service bridges? If so, is that data used in funding allocation and project selection decisions?
3. Following up on FHWA’s reconnaissance trip after the Noto earthquake, what has been Japan’s recovery development process including developing a service restoration plan and communicating with leadership and the public?
4. What processes that aren’t directly tied to addressing deterioration are used to evaluate the need for retrofits or enhancements (for example, seismic retrofit or scour countermeasures)?

Topic 2A: Seismic Retrofit of Bridges and Structures: Retrofitting methods and Programming

1. What are the programmatic principles and procedures for bridge seismic retrofit in Japan?
2. What are the methods for planning bridge maintenance actions in relation/contrast to retrofit actions?

a. Is there a phased approach? Are multi-purpose projects developed to address other structural deficiencies (e.g., load rating, scour, etc.)? Are there special considerations in tsunami inundation areas?
b. How are network performance, life-cycle analysis, life-cycle cost, and remaining service life considered in prioritizing retrofit projects?

Topic 2B: Seismic Retrofit of Bridges and Structures: Target Seismic Performance and Field Observations

1. What damages have been observed on retrofitted structures, and how those damages impact post-event transportation?
2. What are the below-ground retrofits, and what is the observed performance?
3. What are the field performance observations and new recommendations for retaining structures, abutments, embankments, slopes, and drainage?
   a. Have there been improved retrofit recommendations for moisture control (reducing liquefaction), slope stabilization, GRS/MSE for approach embankment, or steep slope at abutment?

Topic 2C: Seismic Retrofit of Bridges and Structures: Durability and Consideration of Other Design/Maintenance Factors

1. What durability issues have impacted seismic performance in actual seismic event, and what are some retrofit measures for deteriorated structures?
2. Have retrofit measures created mechanical issues (local high stress, etc.) or maintenance issues to other bridge features? Please elaborate.
3. What mitigations have you used to increase inspectability and serviceability of retrofit measures and bridge elements adjacent to or affected by seismic retrofit measures?

Topic 2D: Seismic Retrofit of Bridges and Structures: Post-event Management

1. What have been the most significant lessons and/or policy changes in emergency response and recovery after the Noto Earthquake?
2. Does Japan maintain an inventory of temporary bridges for use in emergency response situations? Please elaborate.

Topic 2E: Seismic Retrofit of Bridges and Structures: New Technology and Knowledge Update

1. What recent retrofit technology showed promising performance and value that you may recommend for broad or specific utilization in the future?
2. How do you work with new seismological knowledge (new fault, new models, …) that changes demand estimate? What are the procedures and frequencies of seismic screening or re-screening? How to determine the retrofit/re-retrofit needs because of new knowledge?

QUESTIONS FROM JAPAN DELEGATION TO U.S. DELEGATION

Responses from the U.S. delegation are provided in italic.

Topic 1-1: Asset Management and Data-driven Decision Makings

1. What are the acceptance rates or levels among bridge owners regarding asset management concepts, systems or software?

FHWA: *The United States federal and State bridge community is generally supportive and encourages preservation. They encourage a balance of work types, replacement, rehabilitation, and preservation, moving away from past programs that were predominantly replacement and rehabilitation of bridges in poor condition. An outgrowth of this support has been the growing interest in data driven processes and tools/systems that can quantify the benefits of balanced work programs, assist with forecasting inventory-level needs and investment outcomes, make the case for funding, and assist in selecting bridges and work treatments. The county and city governments vary in their adoption of asset management.*

Minnesota*: There are many Bridge Management Systems and levels of analysis. AASHTOWare BrM, Asset Intel ManageX, and Agile Assets are some software systems that perform Life Cycle Cost Analysis and deterioration modeling as required by TAMP (Transportation Asset Management Plan) for bridges and other assets. Bridge Management Systems are done at network level and not project level.*

Washington: *Bridge Asset management is mandated by federal regulation (like MAP-21). WSDOT's in-house BMS processes are aligned with these requirements. WSDOT developed in-house Bridge Management System (BMS) program integrated with life-cycle cost analysis (LCCA), deterioration modeling, and multi-objective optimization. It is actively used for programming bridge preservation projects.*

Wisconsin: *Data driven tools:*

- *Highway Structures Information System (HSIS) for inspection condition and inventory database/archive.*
- *Wisconsin Structures Asset Management System (WiSAMS) for optimized work recommendations. Work recommendations are updated every 6 months.*
- *Structure Certification Tool (SCT) is utilized to build projects from the WiSAMS work recommendations. The tool facilitates and documents further discussion and unique considerations for each structure within each proposed project.*

Indiana: *INDOT's Bridge Asset Management program has been developed in accordance with our understanding of the federal regulations and collaboration with the FHWA. This process is highly data driven with key areas being housed in fully integrated, enterprise level software. INDOT uses vendor developed, enterprise level software for Bridge Inspection & Inventory (ITAMS), Asset Optimization & Forecasting (DTIMS), geospatial (ArcGIS), and data integration/data warehouse (Oracle). We use in-house applications to manage our Capital/Funded Program (SPMS) and our long-range 20-YR/40-YR program. Data from these* *applications are fully integrated through what we call our data warehouse, allowing data to move between applications without the need for import/exports or manually entered information. The system has greatly assisted our district level bridge asset engineers to maintain their required 20-YR plans and actually go beyond this requirement with a full 40-YR plan.*

2. Do in-house engineers like it [asset management concepts, systems or software] or not? And why?

Minnesota: *The modeling is difficult to calibrate because project level decisions are most of the time not determined by bridge condition. Corridor needs or functional improvements like turn lanes, sidewalks, or wider shoulders sometimes drives project decisions and not TAMP or network analysis.*

Washington*: Many WSDOT engineers appreciate BMS for its transparency, repeatability, and ability to defend programming decisions. It replaces judgment-based ranking with model-based prioritization. However, adoption required training and buy-in process.*

Wisconsin*: HSIS is very user friendly, reports are easy to read. WiSAMS utilizes current asset management policies, which have a variety of input from staff in the areas of inspection, maintenance, design, and financial investment. WiSAMS recommendations are data-driven and policy-driven starting points for discussion of final scope of work.*

Indiana*: Initially there was resistance to this process. Our district bridge asset engineers were accustomed to a score sheet process built into a Microsoft Excel. Score sheets are easier to understand and align with project level thinking. Prior to INDOT executives mandating our 20-YR program, we maintained both our score sheets and our DTIMS forecasting model. During that period, there was very little understanding or utilization of the DTIMS generated result. Once the 20-YR program was implemented, it quickly became clear that score sheets were not adequate for optimizing over a period greater than one year, let alone 20 years. Our current process now allows our bridge asset engineers to start with our DTIMS generated results and then modify as needed for considerations outside the available data. Ultimately we end up with a final, Asset Engineer generated plan that can then be post-analyzed with DTIMS for performance based on deterioration rates. These results can also be graded against the original DTIMS model performance.*

3. What are the regulations and national requirements for the content of the asset management?

FHWA*: 23 USC 119 (United States Code) section (e) State Performance Management assembles text from law and requires that each State develop a risk-based asset management plan for the National Highway System to improve or preserve the condition of the assets and the performance of the system. Included assets include pavements and bridges at minimum. Minimum plan content includes summary data on pavement and bridge inventory, asset management objectives and measures, performance gap identification, lifecycle and risk management analyses, including consideration of risk and resilience, a financial plan, and investment strategies. FHWA must certify the State processes used to develop each State's plan. Recertification is required every four years.*

23 CFR 515 (Code of Federal Regulations) Asset Management Plans expands on 23 USC 119 defining how the law is to be implemented by FHWA and States. This has been in effect since 2017 with the first plans submitted in 2018. States will be submitting their third cycle plan in 2026.

- *Guidance: https://www.fhwa.dot.gov/asset/*
- *State plans: https://www.fhwa.dot.gov/asset/plans.cfm*

4. Do national standards exist for asset management?

***FHWA:** AASHTO and FHWA have many publications that are considered guidance, not necessarily standards or requirements. These are not specific to bridges.*

- *FHWA Guidance: https://www.fhwa.dot.gov/asset/*
- *AASHTO Transportation Asset Management portal has many resources, https://www.tam-portal.com/*
- *AASHTO Transportation Asset Management Guide is a primary resource. https://www.tamguide.com/*

Specific to bridges, the AASHTO Manual for Bridge Evaluation has a brief section that provides guidance on Bridge Management Systems. United States condition assessment publications are considered standards, and include FHWA Specification for the National Bridge Inventory and AASHTO Manual for Bridge Element Inspection.

5. Does a unified or standard indicator exist to explain the efficiency of asset management?

***FHWA:** There are no standardized indicators or measures for the efficiency and effectiveness of asset management.*

We do not have data on efficiency and effectiveness of asset management. We would like to measure efficiency in terms of reduction in time developing work program recommendations and forecasting needs and investment outcomes, as well as the ability to respond quickly to impromptu congressional requests regarding funding needs and outcomes. We have not tracked this nationally. We would like to measure effectiveness in terms of long-term cost savings from applying asset management processes and comparison of forecasted performance measures (for example, average condition rating) with and without asset management processes.

NCHRP Report Return on Investment in Transportation Asset Management Systems and Practices performed analyses to identify hypothetical cost savings from asset management.

6. What is the exchangeability of condition data (and records?) among road owners and states?

***Washington**: WSDOT maintains the Washington State Bridge Inventory System (WSBIS), which houses inventory and condition data for both state-owned and locally owned bridges. Upon request, WSDOT provides relevant condition data to stakeholders. In addition, all state Departments of Transportation, including WSDOT, are federally required to submit annual bridge inventory and condition data in accordance with the National Bridge Inspection Standards (NBIS). This information is transmitted to the Federal Highway Administration (FHWA) and published* *through the National Bridge Inventory (NBI), making condition data readily accessible and exchangeable across states and among road-owning agencies.*

***Wisconsin**: HSIS stores both state-owned and local-owned structures. WisDOT also utilizes the same inspection standards for both. This allows optimization of work recommendations for both state and local structures.*

***Indiana**: I would emphasize how the FHWA established National Bridge Inventory Coding Guide has made bridge data consistent across all states and has made this data readily accessible and exchangeable. Our federal bridge submittal process is a perfect example of how this data is exchangeable. If needed, anyone can obtain data from as many states as they might need. Data from one state should be consistent with data from another state.*

7. Do standard cost evaluation systems and unit prices exist for maintenance, repair, and rehabilitation?

***Washington**: WSDOT developed probabilistic unit cost distributions by analyzing 10 years of bridge preservation project data. These cost models are organized by preservation action type—such as deck rehabilitation, superstructure or substructure rehabilitation, and full replacement—and are calibrated to corresponding NBI condition ratings to reflect varying deterioration levels.*

***Wisconsin**: Preliminary planning and high-level LCCA utilizes rough cost per area estimates to evaluate various work treatments. Construction costs are compiled and summarized each year. Additionally, historical bid item costs are used to generate planning level estimates, especially for rehabilitations, in the scoping process.*

***Indiana**: I would imagine each state has their own standard cost evaluation system. Here at INDOT has developed estimating expressions that we use in our forecasting model. These expressions are based on statistical analysis of past bid histories. These expressions have a unit cost component for typical bridge related items, fixed fee options for appropriate MOT (maintenance of traffic) scenarios and then fixed fee options for various approach roadway related costs. Expressions have been developed for our five (5) primary work types: Thin Overlay, Rigid Overlay, Deck Replacement, Superstructure Replacement and Bridge Replacement. We also have established simple multipliers that can be applied to one of these five to estimate other treatments. It is understood that these estimates are only for budgetary purposes over an extended analysis period and do not replace more detailed scoping estimates.*

8. What are some successful examples of asset management and data-driven decisions?

***Washington**: WSDOT's preservation programming relies on optimization process using deterioration modeling and life-cycle cost analysis. The agency routinely evaluates different funding scenarios, including do-nothing baselines, unconstrained needs assessments, and budget-constrained optimization plans. The output from these scenarios directly informs Capital Program Development Management (CPDM) office to create WSDOT's biennial preservation program.*

***Wisconsin**: Reference WisDOT presentation on deck preservation.*

Indiana: *The success of INDOT's data-driven process has been the evolution of our 20-YR/40-YR bridge program. As described above and in our presentation, our data is fully integrated through our data warehouse and is not only available to our software but to all our bridge asset engineers. When evaluating the results of our bridge optimization model (DTIMS software), our bridge asset engineers have a wide range of visualization tools developed in Microsoft Power BI and can review all strategies generated by DTIMS, not just the selected strategy. This allows our engineers to understand the trade-offs made by DTIMS. Our engineers can then compare this to their own decision making allowing them to improve or see where we might want to improve our model.*

9. What are some examples of budget allocation policies for preventive actions, recovery repair, refurbishment, and replacements based on data analyses?

Wisconsin: *In general, Wisconsin prioritizes bridge work over roadway work. We have historically had strong support for preservation actions, using both maintenance and improvement budgets to accomplish this work.*

Indiana: *INDOT's Bridge Preservation budget is distributed to each of our six (6) districts based on the results of our bridge optimization model. These district level budgets or targets are based on a 5 year average of what the model spends in those districts. While we hold these districts to these targets, we do allow them to select projects different from the model. We do review each district to ensure they are keeping their work type distribution similar to what the model is recommending.*

In addition to providing budget targets to our district, we build visualizations that show how our bridge model work type distribution changes over the analysis period. A good example of this is how we are seeing our bridge model spending 30% to 40% of our total annual budget on bridge replacements in the early years but quickly ramping this up to over 70% as we approach 2050.

10. What are the reactions from users, taxpayers, audits, state finance sections, etc., such as the effectiveness of bridge inspection and management?

Wisconsin: *Public often needs explanation of construction necessity balanced with cost savings. Proposed bridge work fits within overall budget without being overly burdensome. Special federal grant opportunities are pursued whenever possible.*

Indiana: *Our users (bridge asset engineers) regularly state they would not desire to go back to our old scoring system before we had our 20-YR/40-YR program. As noted above, they do not use our DTIMS software output with 100% consistency, but they do lean heavily on it and they appreciate our grading process. No direct feedback has been received from taxpayers but other departments that depend on our bridge programming are very pleased that we have a fiscally constrained 20-YR program.*

11. What are the cost and work burdens (if any) of asset management on smaller-scale bridge owners?

***Wisconsin**: Wisconsin provided substantial assistance to local-owners recently as part of the federal Infrastructure Investment and Jobs Act funding, directing all of these extra funds to the local system. WisDOT has reworked the local bridge assistance program to utilize WiSAMS recommendations as the starting point for approval of local bridge work within the assistance program.*

***Indiana**: It would likely be a significant burden to a smaller-scale bridge owner to fund and develop the entire system that INDOT uses. That being said, INDOT partners with Indiana local agencies to share our bridge inspection and inventory database (ITAMS). INDOT has already started working on a simplified bridge model in DTIMS that could be used for the local agencies. INDOT would be responsible for running the model and then providing the results to each local agency. From a data integration stand-point, this will not be too difficult since all local bridge data is already in ITAMS and integrates to DTIMS. The only work for the local agencies would be to provide INDOT with their currently funded projects (commitments) and to establish their own cost estimating process or adopt INDOT's.*

12. Do you think BMS (bridge management system) or deterioration statistics is suitable for identifying bridges that are likely to collapse or lose the performance? Probably, failure is always a deviation from the trend, and the larger damage extent data is not available that much.

13. Do you feel that people, and sometimes even engineers, often deal with the BMS recommendation, such as priority of bridges regarding maintenance and repair implementations, costs etc., as the truth?

14. Do you have good examples of data management and mining cycles that are used to improve design standards and maintenance practices?

Topic 1-2: LRFR and Retrofit, Rehabilitation, and Repair Design Standards

1. What are the aims and targets of applying LRFR, for example, in terms of
    a. Posting,
    b. Traffic control for vehicles of irregular size or weight,
    c. Retrofit, rehabilitation, and repair design?

Minnesota:

- *Posting – Most states post at the operating level which has a beta of 2.5 for statistical normal distribution of capacity and demand curves. Most states do not use LRFR for posting bridges as current posting equation (Manual for Bridge Evaluation 6A.8.3-1) is too conservative and not calibrated.*
- *Traffic control for vehicles of irregular size or weight – Depending on which agency issues the permit and their policies, trucks may require police escort, restricted driving hours, lead and/or lag escorts, reduced speeds, driving in center of lane to restrict adjacent trucks, and highway closures.*
- *Retrofit, rehabilitation, and repair design – Most states use the rating method that bridge was originally designed in. MnDOT has elected to use LRFR for all bridge projects*

which creates challenges with changing code provisions. Based on project experience, locations that create challenges for LRFD designs are prestressed and reinforced concrete shear (beam, footing, cap) and negative moment for steel continuous beams. Since every bridge is designed for that specific location, we don't have standard details for strengthening or retrofits. Some states have used titanium reinforcement and Fiber Reinforced Polymer for strengthening. Since some of the service life has been extended, MnDOT allows for lower design standards compared to new bridges for rehab/repair projects.

***Washington**:*

- *Posting - Load rating bridges to determine safety of legal loads is the main effort of WSDOT's load rating group.*
- *Traffic control for vehicles of irregular size or weight – Carriers having an overweight vehicle trip will request a permit from WSDOT. WSDOT engineers perform the load rating at no cost to the carrier. This work takes significant resources.*
- *Retrofit, rehabilitation, and repair design – As an example, when we paint a steel bridge, the bridge will experience added temporary weight due to containment, materials, and scaffolding. The bridge needs to be rated to determine whether traffic weight restrictions are needed for the temporary condition.*

***Wisconsin**: We use LRFR for bridges originally designed using LRFD. Occasionally older bridges designed using ASD/LFD are re-rated using LRFR, but we typically stick with the rating method that aligns with the original design method (e.g. LFD LFR, LRFD LRFR). In general LRFR is considered a more reliable and accurate method for design, permitting, and posting decisions for new bridges, but it can be inaccurate for older bridges that were not designed according to LRFD standards.*

2. What are typical cases regarding the timeframe, from identifying a critical fact to restricting the traffic or weight limit for a bridge?

***Minnesota**: FHWA requires the bridge be posted with signs and updated in the bridge management software within 30 days of load rating. For MnDOT typically critical findings due to bridge hits or inspection findings are evaluated within 24 hours for common bridge types. For complex bridges or difficult evaluations, the load ratings can take longer depending on severity of damage, location of damage, evaluation complexity, rating staff availability, and inspection thoroughness. Precautionary temporary lane or bridge restrictions most likely are in place until the bridge can be thoroughly inspected and evaluated. After evaluations are performed, longer term restrictions are installed until repairs can be made if needed. There is no national standard for states for evaluation timeframe from inspection finding to restrictions in place. All compatible Minnesota bridges are in a bridge load rating software (AASHTOWare BrR) database that makes load ratings quick for current or increasing legal load, permit evaluation, deterioration, change in specifications, strengthening options, additional dead load (heavier barrier, sidewalk) projects. Approximately 97% of all (state and local) bridges are in the system. Complex curved steel, arches, cable stay, segmental concrete boxes, and ridged frames are not compatible in BrR currently but influence lines can be used.*

Washington:

- *It takes only a few hours from the time we identify a restriction to when it is officially implemented online. However, it usually takes longer to install a physical posting sign.*
- *When restriction is the result of a regulatory change, it typically takes 30-60 days to install a posting sign. The regulation requires 30 days max.*
- *When the restriction is the result of damage or a condition finding, we will often have the new posting sign installed the same day.*

Wisconsin*: When an inspection is submitted with items noted that could affect the load rating, Load Rating Unit performs an initial review within 7 days of submittal. It then determines if the load rating evaluation should be completed within 30 days or 90 days. If the condition is initially judged to potentially require a restriction, then the 30-day timeline is assigned. Upon completion of the evaluation, if it results in a notification that the bridge must be restricted, the bridge owner has 30 days from notification date to install signs. In all cases, critical findings may require accelerated timelines or temporary closures/restrictions until evaluation is completed, if deemed a safety concern.*

3. What are rules or standards for resistance factors, mode, and investigation uncertainties in the detailed strength evaluation of existing damaged or undamaged bridges, based on detailed investigations?

Minnesota*: LRFR has a resistance factor phi reduction factor for system and condition. See MBE section 6A.4.2.3 and 6A.4.2.4 for details. LRFR posting also has a reduction factor applied per MBE section 6A.8.3 for uncertainties in capacity and concurrent load probabilities.*

Washington:

- *WSDOT generally follows the AASHTO Manual for Bridge Evaluation.*
- *A steel bridge was recently rated due to significant section loss. Many hours of inspection time were spent to measure member and plate thicknesses. The analysis was performed based on the field measurements.*

Wisconsin*: We use AASHTO prescribed factors and methods. However, if there are uncertainties, conservative engineering judgment is considered as part of the evaluation.*

4. What are the rules or standards for load factors and the reference period for loads for retrofit, rehabilitation, and repair design?

Minnesota*: Since the bridge has reduced expected remaining service life, MnDOT allows a lower design load factor of 0.9 HL-93. For high traffic corridors or designated permit routes, MnDOT requires a higher permit truck rating factor. Other factors are evaluated including remaining fatigue life, vertical or horizontal clearance, scour susceptibility, and barrier crash test rating. There is no national standard for reduced load factors for repair projects. An owner may use Weigh in Motion vehicle data to develop site specific calibrated live load factors per MBE C6A.4.4.2.3.*

Wisconsin: *We use AASHTO prescribed methods. For older bridges designed for lighter loads than modern standards, they may occasionally be strengthened during rehabilitation projects to bring them up to modern standards, when feasible.*

5. What are the rules or standards for judging or assessing the traffic closure on damaged or deteriorated bridges?

Minnesota: *Bridge inspectors have authority and responsibility to close a bridge to traffic for safety concern. The inspector would be in contact with a bridge engineer immediately to help make or confirm decision for closure. In depth evaluations would proceed after a thorough inspection is performed. Load ratings would be performed to determine posting or closure levels. Per MBE 6A.8.1 no bridge is allowed to be posted below 3 tons*

Washington: *Our Bridge Design Manual contains some general guidance for when a prestressed concrete girder has been damaged beyond repair vs when it can be repaired. Having written guidance provides greater consistency to our practice. Written guidance also provides better engineering justification when the insurance company for a carrier challenges our recommended repair recommendations after a carrier was found to be at fault for the bridge damage.*

Wisconsin: *An initial assessment is made among the bridge inspectors, load rating engineers, and others for immediate traffic closure. Further evaluation by the load rating engineer may result in long-term traffic closure or weight limit restriction decisions.*

6. What are the rules or standards for judging or assessing whether to replace or continue using existing bridges and case studies?

Minnesota: *The State determines rehabilitation or replacement decisions on many factors including, corridor needs, other functional needs (bike, ped, shoulder), traffic needs, service life after repair, life cycle cost analysis, remaining vulnerabilities (scour, clearances, load capacity) and risks. Rule of thumb is if the cost for repair that lasts 50 years is over 70% for cost of new bridge then replace.*

Washington: *WSDOT had a unique situation this year when we closed the SR 165 Carbon River / Fairfax Bridge. This could be an interesting case study. We could come prepared to share this information.* *https://wsdot.wa.gov/about/news/2025/103-year-old-sr-165-carbon-river-fairfax-bridge-permanently-closed*

Wisconsin: *Condition, rather than load ratings, is the driving factor for rehabilitation scope and timing. However, load rating or weight limit restrictions can be a consideration.*

Topic 2: Seismic Retrofitting Issues

1. Do you see cases where seismic retrofit might have induced distress to the original structural members? For example, structural members were added to steel bridges for seismic reinforcement, and localized corrosion, fatigue cracks, or other distress developed at the connection parts.

2. Do you see cases where seismic retrofit might have construction quality issues with reinforced materials, and so forth? For example,
    a. Cracks developed in concrete jackets.
    b. Any deterioration developed in the resin for FRP sheets.
3. Older bridges may require retrofitting for both live load performance and seismic performance. The reinforcement to fit the bridge with the latest live load requirement may cause an increase in structural weight. In such a case, do you conduct the upgrade of the bridge for live load requirements and seismic requirements simultaneously? Suppose the reinforcement for live loads is discarded and only the seismic retrofit is conducted. In that case, a further seismic retrofit may be necessary when addressing the live load requirement in the future.
4. In typical seismic retrofit projects for steel bridges, do you usually follow through checking the welding details that are prone to fatigue, inspecting existing corrosion and cracks, and taking measures?
5. Could you share your typical practices of durability design in the seismic retrofit or reinforcement projects?
6. When conducting the refurbishment or seismic retrofitting of an existing bridge, do you evaluate the accumulated stress effect and remaining fatigue life, considering the possible earlier and future truck traffic history?
7. Seismic retrofit may indicate that the bridge will be used for a long time. Some guidance may be needed to ask for the durability consideration when an existing bridge is refurbished or seismically retrofitted. Do you have any guidance or rules of durability considerations in your standards, manuals, and other publications for the performance evaluation and refurbishment, retrofit, and repair design for existing bridges?
8. In Japan, we discuss whether it is possible to create standards that require conducting durability design when carrying out seismic reinforcement. Do you have ideas on what should be involved as minimum requirements? For example, ideas are like these:
    a. The stress distribution at the location of an existing structure member where the added structural material or connection is attached may not be changed.
    b. The water treatment or anti-corrosion measures should be given to the connection part of the added structural member or material.
    c. The newly added structural members and materials should be verified for durability over the assigned design period for each project, as well as for each structural member.
9. When conducting a seismic retrofit for a large bridge, do you typically have separate contracts for preliminary design and detailed design?
10. Do you think what should be investigated in research for the use of seismic dampers and buckling restraining braces more frequently in the seismic design of bridges?
    a. For example, dampers and buckling restraining braces typically exhibit a strong directional dependency in mobilizing their damping effect, whereas an earthquake

motion comes from every direction. In such cases, the rules for inputting design seismic motions may be necessary.

   b. Or, the mechanical connection of a damper to an existing bridge member may cause impact effects when the damper is in operation.
   c. In addition, the modification of load and resistance factors, or how to modify them, should be studied, considering the variation of hysteresis curves depending on factors such as fabrication, thermal dependency, velocity dependency, and others.

11. Bridge collapse due to foundation damage appears to be rare in earlier earthquake histories. Do you think the seismic retrofit of foundations should be conducted widely?
12. Do you have ideas to reduce the seismic effect on foundations while protecting the bearings and columns during the seismic retrofit of a bridge?
13. Do you set up measurement/monitoring devices on bridges to record their seismic behavior, so that you can later verify the present practice of seismic response analysis, design, and retrofit?

APPENDIX C TOPIC 1 PRESENTATION SLIDES

U.S. Department of Transportation
Federal Highway Administration

2025 U.S.-Japan Bridge Engineering Workshop

August 4 – 7, 2025

Tacoma, Washington, U.S.A.

U.S. Department of Transportation
Federal Highway Administration

Disclaimer

- Except for the statutes and regulations cited, the contents of this presentation do not have the force and effect of law and are not meant to bind the States or the public in any way. This presentation is intended only to provide information regarding existing requirements under the law or agency policies.

Day 1 Topic Bridge Inspection, Maintenance, and Post-Inspection Actions

U.S. Department of Transportation
Federal Highway Administration

Subtopics

U.S. Department of Transportation
Federal Highway Administration

1. Data-Driven Actions
   A. Preservation and Maintenance Examples
   B. Guidance and Implementation Examples
   C. Risk Management
2. Structural Evaluation and Retrofit Decisions
   A. Performance and Strength Evaluation - Safe Load Carrying Capacity
   B. Extreme Events Evaluation - Retrofitting

U.S. Department of Transportation
Federal Highway Administration

U.S. Group Members

Harjit BAL, New Jersey DOT
Derek CONSTABLE, FHWA
Evan GRIMM, Washington DOT
Erich HART, Indiana DOT
Ed LUTGEN, Minnesota DOT
Philip MEINEL, Wisconsin DOT
Derek SODEN, FHWA
David YANG, Portland State University

(Alphabetic)

U.S. Department of Transportation
Federal Highway Administration

Topic 1-1A
Data Driven Actions
Preservation and Maintenance

Using data to support funding decisions and demonstrate effectiveness

Why use data for decision support:

- objective
- repeatable
- measurable
- efficient (reduce time)
- analytics (including multiple “what-if” scenarios)
- operate within objectives and constraints (budget, condition goals, etc.)

Do we have the necessary data to support decision processes:

- prioritize bridges and work treatments
- identify optimal timing and window of opportunity for work
- quantify investment results (are we spending effectively and achieving what we forecasted)

Using data to support funding decisions and demonstrate effectiveness

Numerous challenges:

- representative data
- quality data
- data variation and scatter (deterioration rates, service life, construction costs)
- predicting service life (for example, new materials or designs)
- building, configuring, and maintaining decision support tools

Still, there are net advantages to data driven decision processes

Separate feature State presentation by Wisconsin will show the data and process they developed for prioritizing and selecting deck treatments.

Topic 1-1B
Data Driven Actions
Guidance and Implementation

Using data to support funding decisions and demonstrate effectiveness

Data types that are used for asset management planning:

- bridge attributes
- bridge needs - condition, risk, mobility
- work action effectiveness (agency and user)
- material/technology deterioration rate or service life
- construction costs

Metrics that are used to communicate to the public our inventory needs and the effectiveness of investment. United States examples;

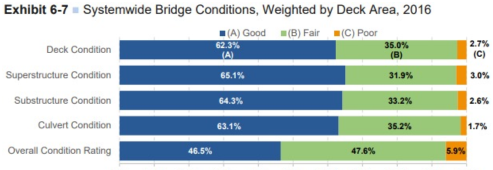
- percentage of bridges classified as Good, Fair, and Poor
- average Bridge Element Index (element condition states)
- average General Condition Rating (0 to 9 condition rating scale)

Using data to support funding decisions and demonstrate effectiveness

- United States examples of communicating funding decisions;
  - State asset management plans:
    - Each State has an asset management plan for bridges on the National Highway System
    - https://www.fhwa.dot.gov/asset/plans.cfm
  - Status of the Nation’s Highways, Bridges, and Transit: Conditions and Performance Report to Congress:
    - Biennial report starting in 1968
    - Communicates national investment needs
    - Uses National Bridge Investment and Analysis System software
    - Multiple scenarios are analyzed, (1) sustain current spending, (2) maintain current condition, (3) improve condition
    - https://www.fhwa.dot.gov/policy/24cpr/

Using data to support funding decisions and demonstrate effectiveness

Exhibit 6-7 Systemwide Bridge Conditions, Weighted by Deck Area, 2016

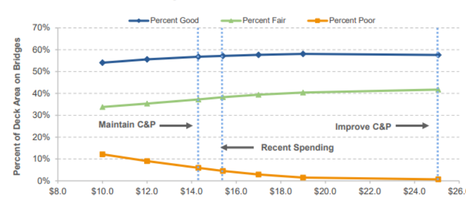


Source: National Bridge Inventory.

Exhibit 7-1 Capital Investment Scenarios for Highways and Bridges and Derivation of Components

Scenario Component	Sustain Recent Spending Scenario	Maintain Conditions and Performance Scenario	Improve Conditions and Performance Scenario	State of Good Repair Benchmark
NBIAS-Derived	Sustain spending on types of capital improvements modeled in NBIAS at the average level over the last 5 years in constant dollar terms over the next 20 years.	Set spending at the level at which the projected percentage of deck area on bridges in poor condition in 2036 matches that in 2016.	Set spending at the level sufficient to fund all cost-beneficial potential projects.	Includes all NBIAS-derived spending included in the Improve Conditions and Performance scenario.

Exhibit 10-15 Projected Impact of Future Investment Levels on 2036 Bridge Condition Indicators for All Bridges



Using data to support funding decisions and demonstrate effectiveness

- Separate feature State presentation by Indiana will present how they use data, metrics, and analysis to support development of network-level investment programs
- Separate feature State presentation by Minnesota will present how they use bridge-level asset management plans

Topic 1-1C
Data Driven Actions
Risk Management

Using data to support funding decisions and demonstrate effectiveness

- Risk-based asset management does not have as much history as condition-based management
- Current data supports semi-quantitative analysis
- We lack representative data for comprehensive inventory-level analysis of extreme hazards, specifically probabilistic bridge demand and response
- Our seismic probabilistic inventory-level analysis capability is more advanced. Uses widely accepted ground acceleration intensity curves and seismic fragility models.

Bridge Risks Addressed

All Bridges

- Deterioration
- Flood and Scour – National Bridge Inspection Standards[1]

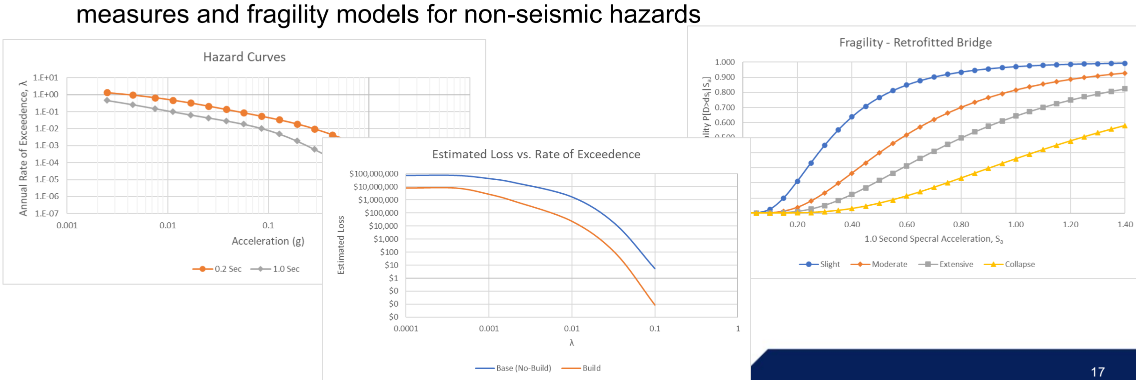
Based on assessment (screening and evaluation)

- Earthquake
- Vessel collision
- Security
- Fire

[1] – 23 CFR 650.313(o)(1)

Using data to support funding decisions and demonstrate effectiveness

- FHWA is researching frameworks for probabilistic inventory-level analysis, and intensity measures and fragility models for non-seismic hazards



Using data to support funding decisions and demonstrate effectiveness

- Separate feature State presentation by New Jersey will present the framework they are developing to quantify bridge risk from hazards and design vulnerabilities

Topic 1-2A
Performance and Strength Evaluation
Safe Load Carrying Capacity

Load Rating in the U.S.

- All bridges must be rated to determine their safe load capacity[1]
  - Represented in terms of truck weight and axle configuration
- Load ratings must be updated when conditions change[2]
  - Inspection identifies deterioration that affects capacity
  - Changes in dead or live loads
- Bridges must be posted to restrict loads that exceed those allowed by the load rating analysis[3]

Source: FHWA

1 – 23 CFR 650.313(k)(1) *3 – 23 CFR 650.313(l)(1)*
2 – 23 CFR 650.313(k)(2)

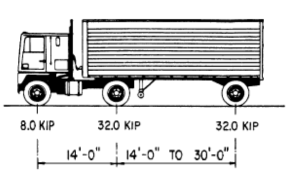
National Load Rating Challenges

- Truck weights have increased over time
  - Older bridges may have been designed for lighter trucks
- Differences between Federal, State, and local truck size and weight laws
  - Difficult to establish uniform loading configurations for rating
- Differences between loading configurations used for design and for evaluation
  - HL93 envelopes Federal legal load configurations but may not envelope State legal load configurations

Design Loads versus Legal Loads

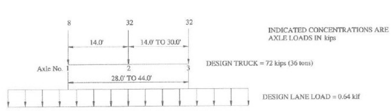
- Design Loads

  Used for structural design and evaluation



HS-20-44

HL93



Source: AASHTO

- Federal Bridge Formula[1]

  Used to determine maximum legal truck weight

$$W = 500\left(\frac{LN}{N-1} + 12N + 36\right)$$

Source: FHWA

[1] – 23 U.S.C 127(a)(2)

National Load Rating Challenges

- Changes in Federal and State laws can lead to a need to reevaluate bridges for new loading configurations
  - Load rating analysis programs can assist, but are not universally implemented
- Standard analysis methods may not adequately consider the effects of severe deterioration

Source: Massachusetts DOT

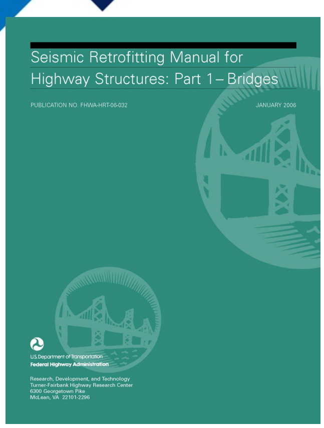
Bridge Load Rating

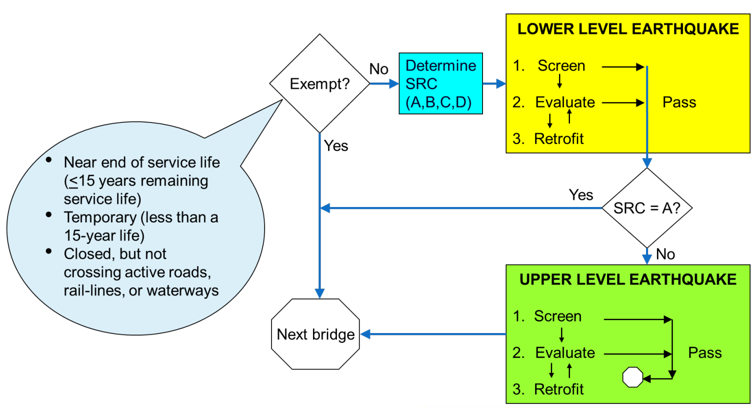
- Feature State presentation by Minnesota (and AASHTO Safety and Evaluation Technical Committee Chair) on bridge load rating and Minnesota's legal and standard permit truck configurations.

Topic 1-2B

Extreme Events Evaluation Retrofitting

Seismic Evaluation Process

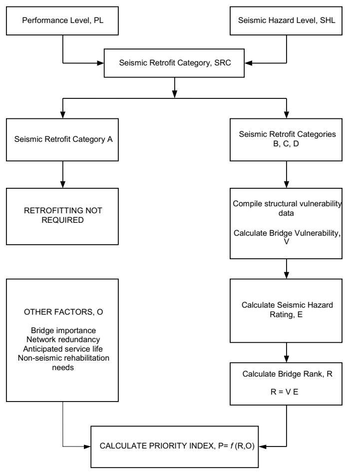




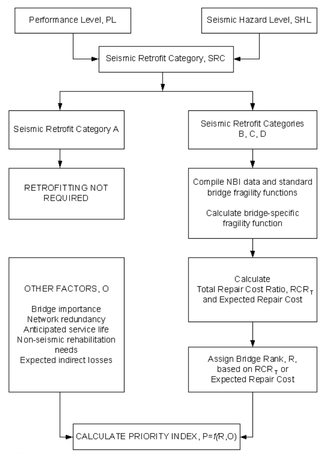
Source: FHWA

Screening Methods

Indices Method

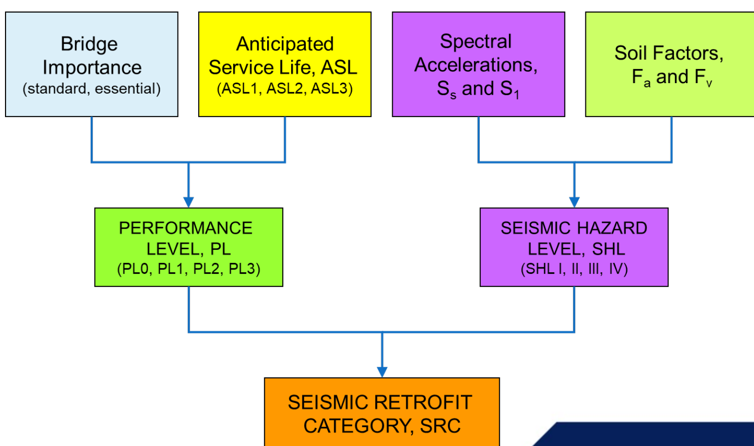


Expected Damage Method



Source: FHWA

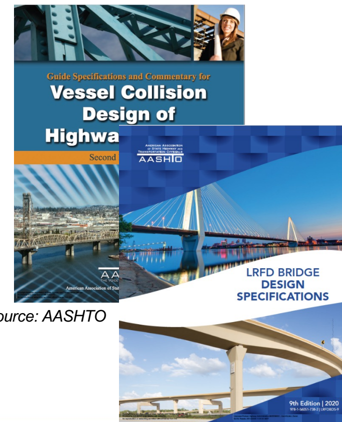
Seismic Screening – Retrofit Category



Source: FHWA

Vessel Collision Screening

- Guide Specifications and Commentary for Vessel Collision Design of Bridges (GSVC) first issued in 1991, updated 2009
  - Developed via FHWA-led pooled fund study
  - Portions incorporated* into LRFD Bridge Design Specifications (LRFD BDS) in 1994
- Three design and evaluation methods
  - Method I – Semi-deterministic $Demand < Capacity$
  - Method II – Probabilistic, produces Annual Frequency of Collapse considering probability of:
    - Vessel aberrancy
    - Geometric probability of allision
    - Bridge collapse due to allision ($D < C$)
    - Effectiveness of pier protection
  - Method III – Method II plus Cost/Benefit Analysis



Source: AASHTO

** - 23 CFR 625.4(d)(1)(v)*

Bridge Seismic Retrofit Evaluations

- Feature State presentation by Washington on their seismic evaluation and retrofit strategy development process.

Wisconsin Data-driven Deck Preservation

Philip Meinel, P.E.
Structures Asset Management Engineer

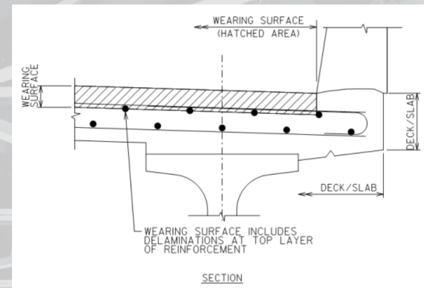
U.S. – Japan Workshop Topic 1-1A
August 4, 2025

BUREAU OF STRUCTURES

How did we get here?

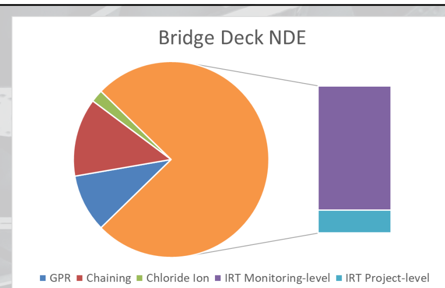
- 2016 Optimizer software
  - Wisconsin Structures Asset Management System proposes work statewide
- 2017 Full program review
  - 800+ state-owned structures within 6 year program
- 2018 Central office approval of all structure work
  - Certification document required
- 2019 Approval software
  - Structures Certification Tool
- 2020 Bridge deck non-destructive evaluation (NDE) program implemented statewide

Which Decks?



- Emphasis on state-owned structures
  - 5,391 bridges (span >20 feet)
- Key National Bridge Elements
  - 12/38 Reinforce Concrete Deck/Slab (77% of inventory)
- Key Agency Defined Elements
  - 8000, 8508-8515 Wearing Surfaces (every deck)
- Key element defects
  - 1080 Delamination/spalls/patching in Deck/Slab underside
  - 3210 Debonding/delamination/spalls/patching in Wearing Surfaces

Which NDE?



- Infrared Thermography (IRT)
  - Level 0 – Aerial IRT
  - Level 1 – Vehicle based IRT with estimated defect quantities
  - Level 2 – Vehicle based IRT with mapped defects
  - Level 3 – Vehicle based IRT with mapped deck preparation areas
- Chloride ion testing (semi-destructive coring)
  - AASHTO T260 water soluble test
- Ground Penetrating Radar (GPR), Impact Echo (IE), and automated sounding as needed

WisDOT Bridge Manual — Chapter 42 – Bridge Preservation

	NBI Item 58	Top Deck Element Distress Area (%)	Bottom Deck Element Distress Area (%)	Preservation Activity	Benefit to Deck from Action	Application Frequency (in years)
	≥7	-	-	Deck Sweeping/Washing	Extend Service Life	1 to 2
		5% < 3220 < 25%	-	Crack Sealing	Extend Service Life	3 to 5
		3220 CS3 + CS4 > 0%	-	Deck Sealing	Service life extended	3 to 5
		-	1080 < 5%	Full Depth Deck Patching	Service life maintained	As needed
		3210 CS3 + CS4 < 5%	1080 < 5%	Wearing Surface Patching	Service life maintained	As needed
		>20% (3220 OR 8911 CS3 + CS4) OR	(1140 OR 1150) < 20% for timber deck	Polymer Modified Asphalt Overlay	Service life extended	10 to 15
		>15% 3210 (applied to bare deck)				
		>20% (3210 OR 8911 CS3 + CS4) OR	1080 < 5% for concrete deck			
		>50% 3220 (reapplication)				
		>20% (3220 OR 8911 CS3 + CS4) OR	(1140 OR 1150) < 20% for timber deck	HMA w/ membrane	Service life extended	5 to 15
		>15% 3210 (applied to bare deck)				
		>20% (3210 OR 8911 CS3 + CS4) OR	1080 < 5% for concrete deck			
		>50% 3220 (reapplication)				
Case 1		3210 < 5%	1080 < 1%	Polyester Polymer Concrete	Service life extended	20 to 30
Case 2		3210 < 2% (applied to bare deck)	1080 < 1%	Thin Polymer Overlay	Service life extended	7 to 15
		8513 CS3 + CS4 > 15% (reapplication)				

Table 42.5-2

Concrete Deck/Slab Eligibility Matrix

Case 1: Polyester Polymer Concrete (PPC)

Case 1: Polyester Polymer Concrete (PPC)

B-40-365

- Bridge Manual guidance
  - Deck NBI rating ≥ 7
    - Delamination 1080 < 1% of the deck underside
  - Delamination 3210 < 5% of the wearing surface
  - If deck age > 20 years old, test chloride concentration

Note: PPC overlays are expensive and new to WisDOT. As a result, use of PPC overlays should be limited to preservation projects that meet the requirements outlined in Figure 40.5-2 or as approved by the Bureau of Structures.

Case 1: Polyester Polymer Concrete (PPC)

B-40-365

- B-40-365 condition
  - ✓ Deck NBI = 7
    - ✓ Delamination 1080 from visual = 0%
  - ✓ Delamination 3210 from IRT = 0%
  - Deck age = 25 years old
    - ✓ Average chloride content = 0.47 lb/cy

Overlay Approved

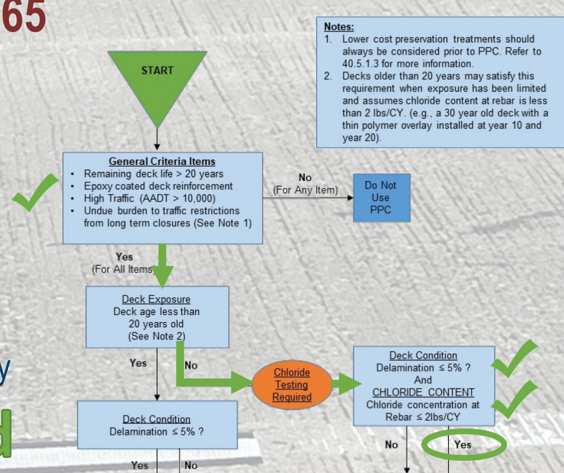


Figure 40.5-2
Polyester Polymer Concrete Overlay Usage Flowchart

Case 2: Thin Polymer Overlay (TPO)

Case 2: Thin Polymer Overlay (TPO)

B-18-161

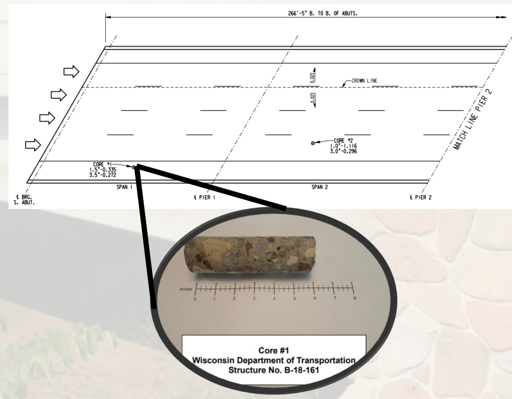
- Bridge Manual guidance
  - Deck NBI rating ≥ 7
    - Delamination 1080 < 1% of the deck underside
  - Delamination 3210 < 2% of the wearing surface
  - If deck age > 10 years old, test chloride concentration

Case 2: Thin Polymer Overlay (TPO)

B-18-161

- B-18-161 condition
  - ✓ Deck NBI = 7
    - ✓ Delamination 1080 from visual = 0%
  - ✓ Delamination 3210 from IRT = 0%
  - Deck age = 16 years old
    - ✓ Average chloride content = 0.45 lb/cy

Overlay Approved



Case 3: Concrete Overlay

B-11-8

- Bridge Manual guidance
  - Deck NBI rating ≥ 6
    - Delamination 1080 < 5% of the deck underside
  - Delamination 3210 > 15% of the bare wearing surface (ADE 8000)

Case 3: Concrete Overlay

B-11-8

- 2020 – Inspector only recorded 16 SF spalling found by visual inspection (36 year old deck)

Elements

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	**12**		**Reinforced Concrete Deck-Coated Reinforcing**	SF	4,190	3,716	472	2	0
		1080	Delamination - Spall - Patched Area Under side of deck at SW and NE corners 2' CS3 **(PIC)**	SF		0	0	2	0
		1130	Cracking (RC) Leaching transverse cracks in all 3 spans.	SF		0	472	0	0
	8000		Wearing Surface (Bare)	SF	3,842	**3,673**	**100**	**69**	0
		3210	Debonding/Spall/Patched Area/Pothole Spalls in SB lane. **(PICS)**	SF		0	0	**16**	0
		3220	Crack (Wearing Surface) Both end blocks need repair. Transverse and longitudinal cracks at ends.	SF		0	**100**	**53**	0

Case 3: Concrete Overlay

B-11-8

- 2020 – Inspector only recorded 16 SF spalling
- 2021 – IRT recommends adding 111 SF CS2 delamination and concrete patching and 12 SF CS3 asphalt patching

Inspection

Edit | History | Interval | Structure information | Condition ratings | Notes / requirements | Documents / images | Maintenance | Deck evaluation

IR

Measured by: AECOM

Notes: A level 1 IR survey was collected at posted speed on 5/5/21.

Time of scan: 05/05/2021 11:50 a

Level: Values Only (1)

Asphalt Patching (%)	Concrete Patching (%)	Debonding (%)	Delamination (%)	Spall (%)
0.3	0.3		2.6	0.0

Validation Methods: None

delete

Case 3: Concrete Overlay

B-11-8

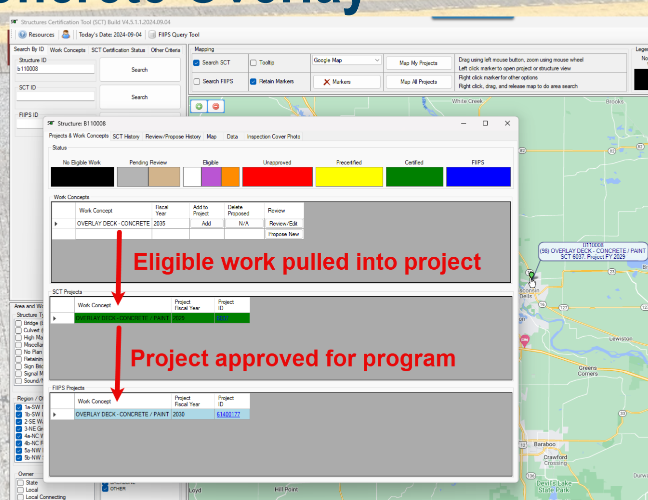
- 2020 – Inspector only recorded 16 SF spalling
- 2021 – IRT recommends adding CS2 qty
- 2022 – Inspector added 111 SF of CS2 delamination (assumes areas of CS3 overlap)

Elements

Chk	Element	Defect	Description	UOM	Total	Quantity in Condition State 1	2	3	4
X	12		**Reinforced Concrete Deck-Coated Reinforcing**	SF	4,190	**3,715**	472	**3**	0
		1080	Delamination - Spall - Patched Area Under side of deck at SW and NE corners 2' CS3.	SF		0	0	2	0
		1130	Cracking (RC) Leaching transverse cracks in all 3 spans. **Heavy efflorescence under SE corner of deck.**	SF		0	472	**1**	0
	8000		Wearing Surface (Bare)	SF	3,842	**3,562**	**211**	69	0
		3210	Debonding/Spall/Patched Area/Pothole Spalls in SB lane. **May 2021 Level 1 IR deck survey indicates 0.3% asphalt patching, 0.3% concrete patching, 2.6% delamination and no spalling.**	SF		0	**111**	16	0
		3220	Crack (Wearing Surface) Both end blocks need repair. Transverse and longitudinal cracks at ends.	SF		0	100	53	0

Case 3: Concrete Overlay

- Visual only inspection
  - No work action
- Visual with IRT results
  - 2035 concrete overlay



Programmatic Savings with NDE

Transition scoping methodology from typical service life to projected component and element condition

- 2017 full program review provided a rare opportunity to compare different scoping methods
  - Estimated project savings of $24M per year
    - Avoiding unnecessary overlays, deck replacements, and even full replacements with improved element condition estimates from NDE
  - Redirect funds to preservation activities
    - In 2019-2021, funds were redirected toward thin polymer overlay applications

WISCONSIN DEPARTMENT OF TRANSPORTATION

Thank you!

Philip Meinel, P.E.

Structures Asset Management Engineer

Philip.Meinel@dot.wi.gov

BUREAU OF STRUCTURES

QUANTITATIVE AND PERFORMANCE-BASED DURABILITY DESIGN BASED ON ACCUMULATED CONDITION DATA

PUBLIC WORKS RESEARCH INSTITUTE

HIROHISA KOGA

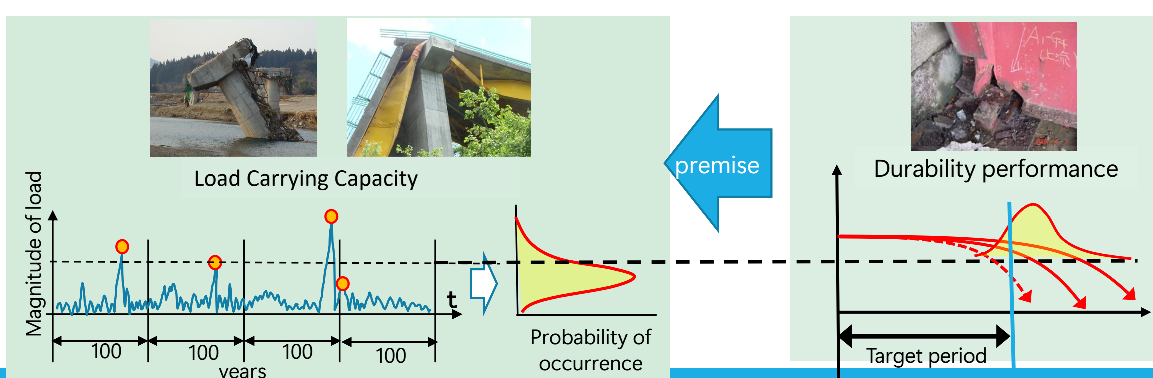
Durability Design in Japanese Code

* **Definition of durability performance of bridges**

  Performance in which the load-bearing capacity of a bridge is not affected by age-related deterioration with the required reliability.

* Durability period

  Standard design service life is 100 years. Designers must design the bridge to ensure its durability performance, considering the planned maintenance.



Issues in Durability Performance Design

＊Required reliability

"Required reliability" is not defined quantitatively.

When applying new materials and structures, the same level of durability as conventional materials should be required, but it is not easy to determine this.

There are various factors to consider in terms of durability, such as corrosion and fatigue of concrete and steel members.

Only the fatigue resistance of joints in steel components, it is demonstrated the level of reliability explicitly.

The fatigue strength of joints is based on the fatigue test results for each joint and is set at a value with a 97.7% probability of not breaking.

Examples of specification regarding durability performance

＊Corrosion of steel bars in concrete in coastal area

In Japan, corrosion due to chloride ions (Cl^-) is a major factor contributing to the serious deterioration of bridges.

Corrosion due to Cl^- became apparent in the 1970s in Japan. It is because, many bridges were built after the world war II.

severely deteriorated bridge decades after construction

Measures to ensure durability against corrosion due to Cl^-

In order to prevent large amounts of chloride ions from reaching the steel reinforcement, increased concrete cover, epoxy-coated reinforcement, surface painting are adopted in 1987 and modified in 2002.

It is based on the results of surveys of bridges damaged in the 1980s.

In the regions of severe chloride environment, epoxy-coated reinforcement or surface painting shall be used with providing adequate concrete cover.

Regional division

environmental class

Region	Distance from shoreline	Class
A	up to 100m	S
	100 to 300m	I
	over 300m	II
B	up to 100m	S
	100 to 300m	I
	300 to 500m	II
	500 to 700m	III
C	up to 20m	S
	20 to 50m	I
	50 to 100m	II
	100 to 200m	III

Minimum concrete cover (mm)

Severity	Class	PC (precast)	PC (in-situ)	RC
Severely Affected	S	70[1)]	70[1)]	70[1)]
Affected	I	50	70	70[1)]
	II	35	50	70
	III	25	30	50
W/C ratio (assumed):		36%	43%	50%

Note 1): It shall be used epoxy-coated reinforcement or surface painting in conjunction with providing adequate concrete cover

Data-driven durability verification

* Survey in the 1980s

The effectiveness of the provisions was examined with observation data of 920 concrete structures located within 500 m from the shoreline.

Based on visual observations, the possibility of future deterioration has not been verified.

* Current study

Now we are trying to verify the reliability of corrosion not starting during the design service life (100 years), based on data of chloride ion concentration in concrete.

Dataset 1 : Data in research papers

Dataset 2 : Inspection data

Dataset 1 : data in research papers

＊Data from exposure test

Data was collected from reliable researches.

80 sites in Japan.

Exposure periods is between 2 and 20 years.

The type of cement is ordinary portland cement or high-early-strength portland cement.

There are app. 160 data in total.

Data was classified by the water cement ratio (W/C) of concrete

- 36% or less PC (precast)
- between 36 and 43% PC (in-situ)
- more than 43% RC

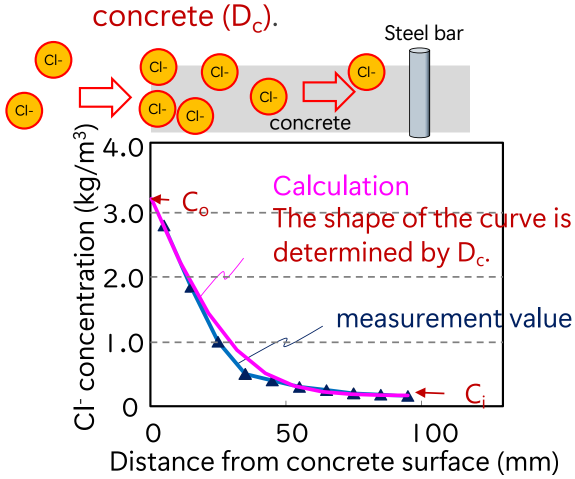
Typical exposure sites

Evaluation method for resistance to the corrosion due to Cl^-

＊Fick's diffusion equation

Ingress of Cl^- in concrete can be explained as concentration diffusion of Cl^-.

By analyzing the distribution of Cl^- concentration in concrete, it is possible to analyze the Cl^- supply environment (C_0) and the quality of concrete (D_c).



Fick's Second Law of Diffusion

$$C(x,t) = C_0\left\{1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right\} + Ci$$

C_0 : Cl^- concentration at concrete surface (kg/m^3)

D_c : Diffusion coefficient of concrete (cm^2/year)

C_i : Initial Cl^- concentration (kg/m^3)

Evaluation method for resistance to the corrosion due to Cl^-

* The time of corrosion initiation can be calculated from C_0 and D_c.

C_0 : Cl^- concentration at concrete surface (kg/m^3)

D_c : Diffusion coefficient of concrete (cm^2/year)

C_i : Initial Cl^- concentration (kg/m^3)

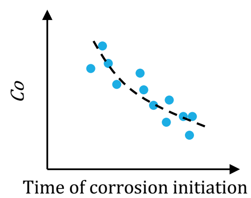
C_{lim} : Cl^- concentration which start corrosion(kg/m^3)

$$C(x,t) = C_0\left\{1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right\} + Ci$$

↓

$$t = \left\{\frac{x}{\omega^{-1}\left(1 - \frac{C_{lim} - C_i}{2C_0}\right)}\right\}^2 \cdot \frac{1}{2D_c}$$

→

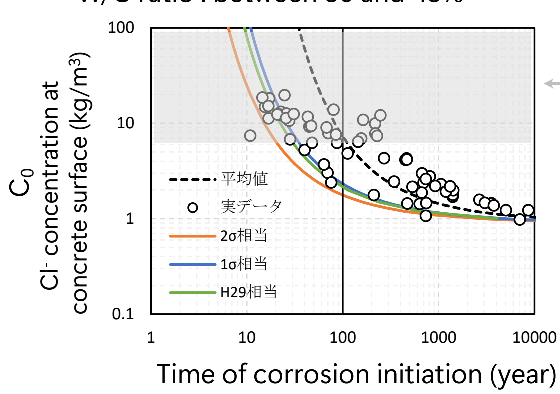


Analysis of existing data in research papers

Based on the available data, it is estimated that there is a certain probability that corrosion will not occur over a period of more than 100 years.

However, only a limited number of research reports provide sufficient information and it is not possible to quantitatively define reliability.

Cover concrete : 70mm width.
W/C ratio : between 36 and 43%



Where is high Cl supply, epoxy-coated reinforcement or concrete coating in combination with increased concrete cover are required.

Most of data shows that corrosion not starting during the design service life (100 years).

Dataset 2 : data from bridge inspection

＊Special inspection in coastal area

Introduced in 2015.

In order to encourage preventive measures against corrosion due to Cl^-, the distribution of Cl^- in concrete is surveyed once every 10 years.

However, it appears that the preventive maintenance cycle using the results of these inspections may not be functioning properly.

The reasons for this are the cost of the investigation and the impression that it may damage the sound structure.

＊Number of data

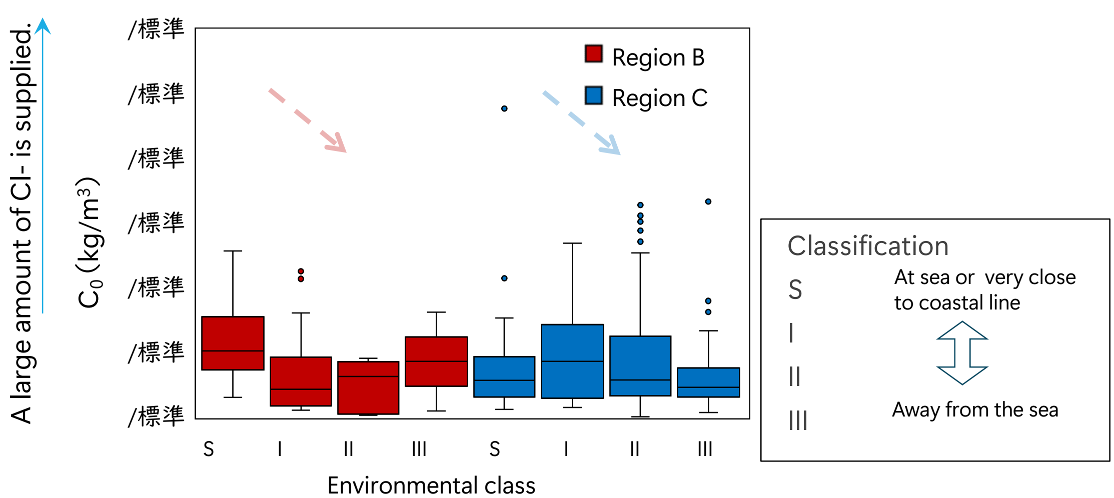
RC bridge : 114

PC bridge : 350

Analysis of data obtained by bridge inspections

＊Cl^- concentration at concrete surface (C_0, kg/m^3)

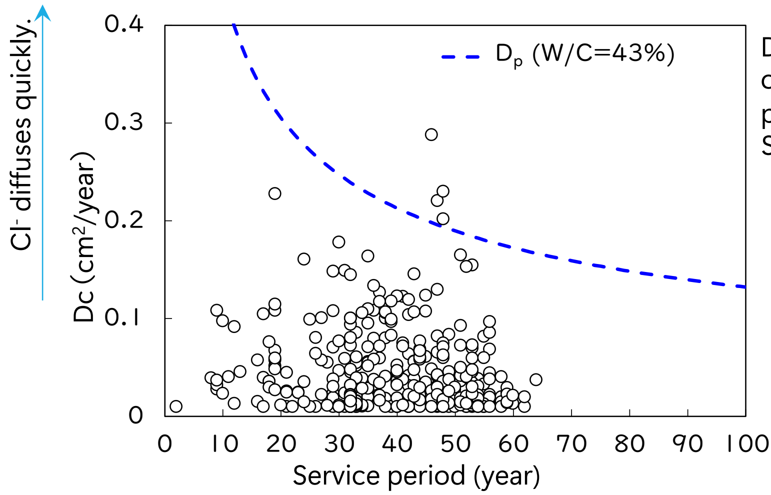
The stricter the classification, the greater the supply of chloride ions. However, there is also greater variation of data.



Analysis of data obtained by bridge inspections

＊Diffusion coefficient of concrete (Dc, cm²/year)

The diffusion coefficient estimated from the inspection data tends to be generally smaller than the predicted value.



Dp: Predicted diffusion coefficient, based on the prediction formula of the Japan Society of Civil Engineers

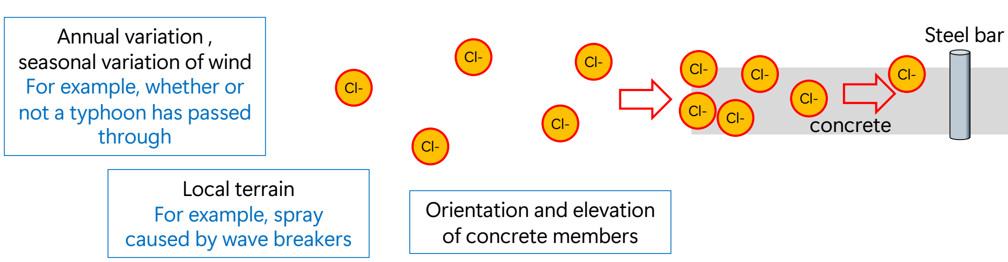
Future Works

＊Separation of environmental factors and resistance factors

Currently, only regions, distance from shoreline and quality of concrete are considered.

Looking at the analysis results, there is a large variation in the salt supply environment (C_0).

In order to utilize performance-based durability design, it is necessary to appropriately analyze and organize the factors that affect reliability.



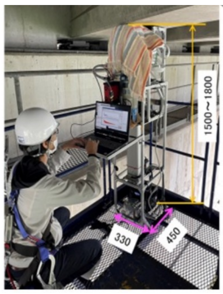
Possible factors contributing to large variation of C_0.

Future Works

＊Adapting to new survey techniques

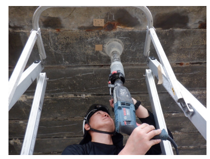
In order to encourage preventive measures against corrosion due to Cl^-, it is necessary to promote the use of simpler inspection methods.

On the other hand, the quantity and accuracy of data obtained by simpler inspection methods may be limited.



Non-destructive Cl content measurement using neutrons
(BR020032—V0225)

Source : Inspection Support Technology Performance Catalog, MLIT
https://www.mlit.go.jp/road/sisaku/inspection-support/zenbun.html



Sampling drill dust

fluorescent X-ray analysis

Salt content measurement with small samples using fluorescent X-ray analysis

Summary:
Verification on resistance to corrosion due to Cl^-

＊It is estimated that bridges constructed under current regulations will have a close to 97% probability of not starting to deteriorate for 100 years, even in areas prone to salt damage.

＊However, further data accumulation is necessary to quantitatively demonstrate reliability.

＊Using inspection data is an effective way for collecting large amounts of data, but there are outliers.

＊The challenge is that detailed information necessary for analysis, such as detailed concrete composition information, is difficult to collect from general inspection data.

US – Japan Bridge Workshop
Topic 1-1B Data Driven Actions

Erich Hart

Indiana DOT - Bridge Asset Management

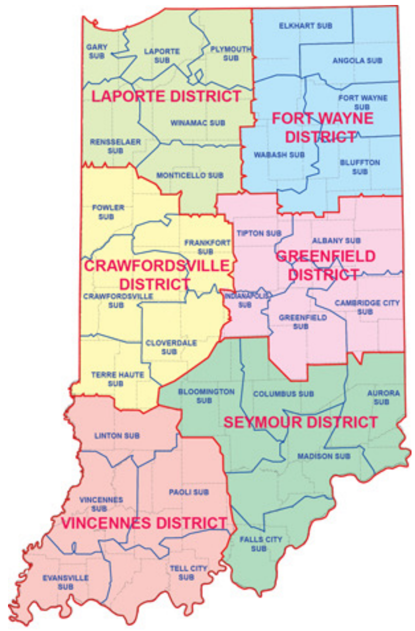
August 4th, 2025

INDOT Bridge Assets & Districts

- **Executive Summary**
  - Indiana Bridge Assets & Districts (Size and Organization)
  - Annual Bridge Preservation Budget
  - District Budget Target Distribution (2 slides)
  - Why not let our model make all the decisions?
  - Why require our bridge asset engineers to do a 40-YR plan?
  - Keys to Successful Program
  - INDOT Asset Management Software

INDOT Bridge Assets & Districts

- **6 Districts (5,776 state bridges)**
  - Crawfordsville: 914 Bridges
  - Fort Wayne: 764 Bridges
  - Greenfield: 1,233 Bridges
  - LaPorte: 838 Bridges
  - Seymour: 982 Bridges
  - Vincennes: 1,045 Bridge
  - Total INDOT: 5,776
  - Total Indiana: 19,513



INDOT Bridge Preservation Budget

- **Bridge Preservation Annual Budget**
  - $470 million/ YR Present Value
    (fiscal year 2026, assume 2.35% inflation)
  - Call for Bridge Projects (5 years out: 2031)
    - Minor – Thin Overlay, Rigid Overlay, Paint, Scour
    - Major – Deck Replace, Superstructure Replace, Bridge Replace
  - Budget Breakout
    - $**370 million/YR:** Preservation (major/minor)
    - $24 million/YR: Preventive Maintenance (PM)
    - $20 million/YR: Border Bridge Projects
    - $56 million/YR: Large Culvert Program (>48 inch)

District Budget Target Distribution

- **Bridge Preservation $370 million/YR: (major/minor – from previous slide)**
  - The $370 million/year remaining for major and minor projects is distributed to each district <u>based on the results of our bridge optimization model</u>
  - Fairest way to distribute funds to our districts
  - We have business rules for how much a district may deviate from these targets during the planning year and prior to a given year being programmed

INDOT Bridge Preservation Targets

- **Why do we have targets?**
  - We (Indiana Bridge Asset Management) learned the hard way if we don't provide annual targets and just ask each district what their bridge needs are, each district would spend the entire budget each year.
  - Just about any bridge has some kind of need at any point in its service life so trade-offs must be considered.
  - By providing targets to our districts, we guided them into making trade-off decisions with their plans and spread their bridge needs out over the 40 year analysis period.

INDOT Bridge Preservation

- **Why not use exactly what the optimization software (DTIMS) recommends?**
  - Our DTIMS model is a network level model – Limited
  - While we believe our DTIMS model is a good model and provides excellent analysis of our network, it is limited to the data consumed, the treatments considered, and the rules we code into our model.
  - A project level model would be the "Gold Standard" but very hard to achieve and would require much more detailed data than we currently collect with our inspections. Also, much harder to validate.

INDOT Bridge Preservation

- **Why does INDOT require our bridge asset engineers to do a 40-year plan?**
  - The goal is a good 20-year plan
  - To ensure the projects (and trade-offs) picked are beneficial long term, one must see the resulting future needs and how they compare to the future budgets.
  - This is done by the software but is hard to enforce with our asset engineers if they are not feeling the same "pain" the software feels.
  - Because we allow our districts to propose alternate plans versus the software, we need comparable analysis periods for "grading"

District Targets – Business Rules

Allowable Target Deviation

	2031 Call	2032 Call+1	2033 – 2035 Next 3 YR's	2036 – 2045 Last 10 of 20	2046-2065 Last 20 of 40
Allowable Yearly Delta	0%	2%	5%	10%	20%
Check Aggregate Years	Not Applicable	Not Applicable	3 Year Aggregate	10 Year Aggregate	20 Year Aggregate
Allowable Aggregate Delta	Not Applicable	Not Applicable	3%	3%	3%

- **First 5-Years:** Capital Program – Already Funding (2026-2030)
- **Call:** Call for Projects. Forecasted projects selected for funding (2031)
- **Delta:** +/- amount each district may deviate from assigned budget target
- **Targets:** % of annual bridge preservation budget forecasted for each district by optimization software (DTIMS BA)

INDOT Keys to Bridge Asset Mgmt

- **Committing to a Long-Range Plan (20YR/40YR)**
  - Budgets fully spent and trade-offs recognized
  - Update this plan every year
- **Quality Data (Inventory, Condition, Capital Program)**
- **Digital Tools / Software**
  - Inventory/Inspection Database, Capital Program Application, 20YR/40YR Plan Application, Bridge Optimization Model
- **Software Integration**
  - Direct data transfer (Communication)
  - INDOT Data Warehouse (Oracle)
- **Business Visualization**
  - Various reports for interrogating the data

INDOT Asset Management Software

- 20YR/40YR Plan Application
  - Where districts develop their fiscally constrained plans
  - Track budget versus spending & work type distribution
  - Integrates back to model for post-analysis
- Capital Program (SPMS Application)
  - Manages INDOT's funded projects
- Forecasting/Optimization Tools
  - dTIMS BA (Deighton Inc.)
    - Network Level Optimization software
    - Integrated with Inventory, GIS, Capitol Program & 40YR Plan
    - Forecasts district budget targets and work type targets

- Bridge Inventory Database (ITAMS)
  - Stores FHWA Required Data & Inspection Reports
  - Backbone for everything else
- Data Warehouse (Oracle)
  - Facilitates live integration of the above data

Bridge Management Plan for Individual Bridges

DEPARTMENT OF TRANSPORTATION

Ed Lutgen| MnDOT State Bridge Engineer

Network Level vs. Individual Bridge Plans

- Network Level
  - Averages, typical, program level bridge
- Bridge Management Plan
  - Designed to Individual bridges
  - More detail than typical safety inspection condition information and what is in Bridge Management System (BMS)
  - Provide matrix of options and recommendations for future projects

Scenario – Deck Work Type	Will this action extend life until 2040?	Life Cycle cost over 50 years (Replacement not included)	Life Cycle cost over 25 years (Replacement not included)
#1 – Deck Repair	No - Unlikely	$45 million	$41 million
#2 – Limited Service OL	Yes - Most Likely	$42 million	$14 million
#3 – HydroDemo and silica fume OL	Yes – With some substructure repair	$53 million	$19 million
#4 – Redeck, no super or sub work	Yes – With some substructure repair	$46 million	$42 million
#5 – Redeck with new Super and Sub	Yes	$75 million	$65 million

Types of Bridge Management Plan

- Complex Bridges
- Historic Bridges
- Unique Bridges
- Complex corridor

Minnesota Department of Transportation (Mn/DOT)
Historic Bridge Management Plan

Bridge Number: 9036

Executive Summary

Bridge 9036 (Robert Street Bridge) was built in 1926 to carry vehicular traffic on U.S. Highway 52 (Robert Street) over the Mississippi River in downtown St. Paul, Ramsey County. It has an overall structure length of 1,428.9 feet and an out-out width of 80.4 feet, with eight reinforced-concrete-arch main spans and nine prestressed-concrete-beam approach spans. The main spans include three open-spandrel barrel arches, four open-spandrel rib arches, and a 264-foot, rib through-arch (rainbow arch) over the navigation channel. The massive ribs of the rainbow arch give the bridge its identifiable profile and provide a gateway for motorists entering downtown St. Paul. Because of its prominent urban location it received architectural detailing in the Moderne style. A 1989 reconstruction included replacement of the deck and approach spans, restoration of the arch spans, and reconstruction of the ornamental railing.

Bridge 9036 is generally in fair condition. It has adequate deck width and load capacity. The primary concerns for Bridge 9036 are conveyance of deck and sidewalk drainage and deterioration of several concrete components.

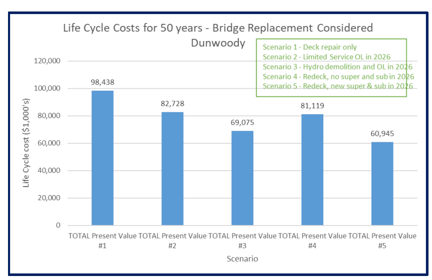
The recommended future use of the bridge is rehabilitation for continued vehicular use on-site. The bridge should be rehabilitated based on the Secretary of the Interior's Standards for Rehabilitation (Standards) [36 CFR Part 67] and Guidelines for Bridge Maintenance and Rehabilitation Based on the Secretary of the Interior's Standards (Guidelines).

Until the Federal Highway Administration (FHWA), State Historic Preservation Office (SHPO) and Minnesota Department of Transportation (Mn/DOT) have signed a historic bridge Programmatic Agreement, all proposed work on this bridge (including maintenance, preservation and stabilization activities) needs to be sent to the Mn/DOT Cultural Resources Unit (CRU) for formal review.

MEAD & HUNT HNTB JUNE 2006

Evaluation

- Element and product specific deterioration modeling (bearings, joints, cables, etc)
- Life Cycle Cost Analysis (LCCA)
- Use all strategies do nothing, preventive maintenance, cyclical maintenance, preservation, rehabilitation, and replacement
- Develop matrix of options that each year has strategy (combination on all strategies)
- Major or complex bridges develop option that keeps bridge in perpetuity of good condition. ≠ Budget buster.

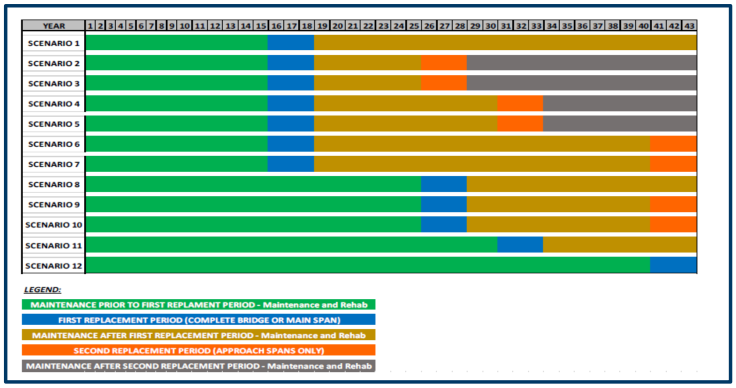


EPOXY COATED REINFORCEMENT DECKS

Rebar Age (Yrs)	Deck NBI	Element 510 Deck Wearing Surface %	Crack Density LF/SF	Deck Underside Element 12	Repair Option	Repair Notes	Repair Alternate No.	Potential Result to Deck NBI	Anticipated Service Life range (low to high)		Reinf. Service Life Extension
<30	> 7	N/A	≤ 0.17	N/A	Seal Cracks With Epoxy By Chase Method		1	No change	5	7	+ 10
<30			> 0.17		MMA Flood Seal		3	No change	5	5	+ 10
Any		<5	≤ 0.17	<2%	Polymer W.C. Type Epoxy		8	+ 1	7	15	+ 5-20
			> 0.17		Polymer W.C. Type Epoxy with Pretreat		9	+ 1	7	15	+ 5-20
			Any		3/4" PPC Concrete W.C.		11	+2, max 8	25	35	+30
Any	>6	≤ 3	≤ 0.17	< 10%	Local Patching Type D-F and Seal Cracks by Chase Method		4	+ 1	15	15	+5
			≤ 0.17		Local Patching, 5/8" UTBWC and PPC at Exp. Jt Headers		6	+2, Max 7	15	15	+10-15
			> 0.17		Local Patching Type D-F with MMA Flood Seal		7	+ 1	12	17	+5-10
		3-10	Any	< 10%	Local Patching Type D-F with MMA Flood Seal		7	+ 1	5	10	+3
≥30	≥5	3 - 20	Any	< 20%	Mill and 3U17A Conc. W.C. with Type A - C Patching		12	+2, Max 7	30	10	+20
					Mill and Microsilica W.C. with Type A-C Patching		13	+2, Max 7	30	30	+20
		15-30		< 10%	Hydrodemo and 3U17A W.C.		14	+3, Max 7	40	40	+30
					Hydrodemo and Microsilica W.C.		15	+3, Max 7	40	40	+30
≥40	4-5	20 - 30	Any	10 - 40	3" Concrete W.C. (3U17A) -Limited Service		16	+2, Max 6	10	15	+5
≥50	≤ 4	>20	Any	>20%	Redeck		17	9	75	100	+75

Recommendations

- For BMP, identify several possible ways to manage bridge over the next X years
- Help identify scope of next project (cost, schedule, traffic impacts, construction duration, estimate quantities).
- Helps planners and accountants to merge pavement and other assets needs into 1 project.



Dunwoody Bridge Management Plan

- Dunwoody bridges: constructed in 1969, 50 bridges, 1 tunnel, 180,000 ADT
- Slight to severe concrete deterioration with rebar corrosion.
- A long-term BMP was created to consider the condition of major bridge elements such as deck, joints, beams, and piers and expected life and how they relate to each other.

Scenario Definitions	Scenario #1 - Emergency deck repairs only, no preventative maintenance, replace once deterioration is extensive
	Scenario #2 - Limited Service OL in 2026 but no deck repairs, some preventative maintenance, avoid rehab
	Scenario #3 - Replace OL and repair deck using hydrodemolition in 2026, some deck preservation
	Scenario #4 - Replace Deck in 2026. No rehab of piers, just patch as needed.
	Scenario #5 - Replace Deck in 2026. Major rehab of superstructure and substructures. Preservation performed

Thank you again!

Edward Lutgen

Edward.Lutgen@state.mn.us

651-366-4507

Performance and damage data collection in bridge inspection

August, 2025

Masahiro SHIRATO
Bridge and Structures Division, NILIM, MLIT

Contents

1. Bridge inspection record structure in Japan
    - Maintenance and repair policy classification for each bridge
    - Performance evaluations for its superstructure, substructure, and super-substructure link, respectively
    - Damage/symptom data recording --- Segmental data recording

2. Issues in Japan on how to use the data

Bridge inspection code and record structure

Road law

Engineering part

Ordinance & Notice (Mandatory)

- Frequency = 60 months
- The Inspector conducts hands-on observations and makes a comprehensive diagnosis.
- The Owner categorizes the bridge's maintenance policy:

I. None of the below
II. Preventive maintenance in terms of durability is highly recommended.
III. Repair work is required by the time of the next inspection.
IV. Immediate action is needed, such as closing traffic.

Technical advice, quality-wise (Standards)

- The diagnosis record involves engineering evaluations:
  - Load-carrying capacity performance
  - Durability performance

Fact/data recording part

The way and format of recording bridge distress/defects are at the owner's discretion.

Recommendations

- Objective damage data recording protocol

← Asset management & Data compatibility

✓ **Must report the maintenance policies of all road bridges to MLIT**

Requested to report to MLIT

https://www.nilim.go.jp/lab/ubg/english/research.html

Load-carrying performance speculation: Loads vs Resistance

(Not calculate or test)

Rare but possible situations by the time of the next inspection

- ☐ **Live loads** with simultaneous multiple heavy vehicles, which is rare but possible in the ordinary traffic flow on the bridge
- ☐ **Earthquakes** with an intensity that prompts the owner to conduct a post-event patrol as their in-house rule.
- ☐ **Heavy rain/flooding** due to typhoons and monsoons

Situations / Components	Live loads	Earthquake	Heavy rain/floods	Others
Bridge system				
Superstructure				
Substructure				
Super-sub structures link				
Expansion joints				
Fail-safe				

Speculated Functional States at each situation;

A: **The bridge is unlikely to have damage** or irregularity that leads to the bridge's dysfunction.

B: **Neither A nor C;** the bridge may result in dysfunction.

C: **The bridge may fall into a critical state**, such as collapse, closure, considerable load limitation, etc.

Durability performance evaluation

- Record the presence or absence of the given deteriorations and phenomena
- Flagging the bridges with the potential needs of preventive maintenance
- Empirically influenced bridge life cycle costs in Japan

	Fatigue	Chloride ingress	ASR	Scouring	Others
Superstructure					
Substructure					
Super-sub structures connection					
Expansion joints					
Fail-safe					

Y / N

Goal: Improving the performance of bridge (road) networks

Refurbishment, recovery, and maintainance of bridges in service

Asset management (Data driven)

No national codes & standards

New bridges — **Equivalent** — Bridges in service (Inspection)

Load-carrying performance

	Load-carrying function		Structural safety
	Intact	Limited function	Avoid a critical state
100-year peak values	X		X
Accidental situations		[X]	X

Supplemental performance
- Expansion joint
- Fail-safe

Durability performance

- Load-carrying performance
  - ✓ Situations versus load-carrying states

Situations / Components	Live loads	Earthquake	Heavy rain / floods
Bridge system			
Superstructure			
Substructure		A, B, C	
Super-sub structures link			
Expansion joints			
Fail-safe			

- Durability performance

  Y or N

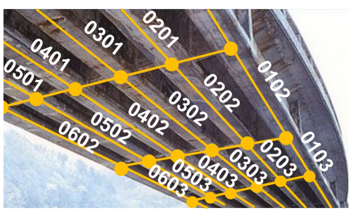
Objective damage recording (Fact data recording)

- MLIT views its 24,000 bridges as samples (a variety of ages; diverse traffic and environmental conditions) and records the facts of damage to conduct scientific and statistical analyses at the national level.
- MLIT also recommends a compatible or less sophisticated version of the segmental data recording protocol for ordinary bridge owners to obtain damage data for their asset management..

Segmental data recording in MLIT (Starting in 2006)

- Structural members are subdivided into DRSs.
- DRSs are assigned to 20 major structural elements and some others.
- Each DRS has an ID and the information on the 5-tier extents of damage for the designated 26 defect types.

Data Recording Segments (DRSs)



Extent of damage	Numeric criteria for appearance		
	Maximum crack width		Minimum crack distance
	Reinforced concrete (RC)	Prestressed concrete (PC)	
'a'	No or hair crack		
'b'	< 0.2 mm	< 0.1 mm	≥ 0.5 m
'c'	< 0.2 mm	< 0.1 mm	< 0.5 m
	0.2 — 0.3 mm	0.1 — 0.2 mm	≥ 0.5 m
'd'	0.2 — 0.3 mm	0.1 — 0.2 mm	< 0.5 m
	≥ 0.3 mm	≥ 0.2 mm	≥ 0.5m
'e'	≥ 0.3 mm	≥ 0.2 mm	< 0.5 m

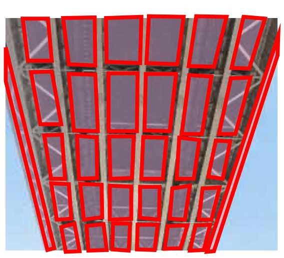
Compatible version for ordinary bridge owners

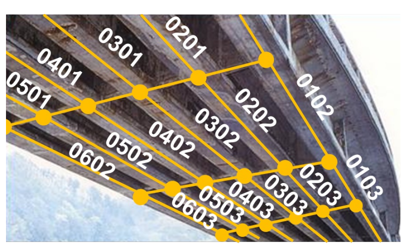
- Reduced number of segments
  - Reduced segmentations
    - ✓ e.g. Girder-end
      – Intermediate
      – Girder-end
- Reduced number of defect types
  - ✓ 26 → 13
- Reduced number of damage extents
  - ✓ 5 to 2-tier classifications

Segmental data recording: Segment mapping information

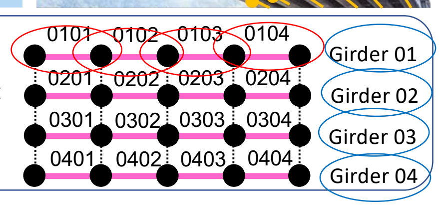
- Each segment is bounded by the other landmark structural members.
- DRSs are subdivided portions of individual structural members at individual spans.
- Each DRS has a segment ID number.

Data recording segments = dot-to-dot or panel-to-panel





e.g., every single girder is subdivided at the position of floor beams in a span



Classification of “the extent of damage” appearance: Fact records

- Damage extent is not of engineering significance, as it does not consider the difference in the importance of element types, such as main beams or lateral beams, nor the causes of damage, such as excessive loading or reinforcement corrosion.
- Not include the inspector’s views on the need for repair or maintenance in the classification. They must record the observed appearance as it is by strictly following the definitions and photographic examples in the manual.
- Objectivity is crucial in ensuring that the data analysis results accurately reflect the facts.

Concrete cracking

Least → Worst (5-tier)

Extent of damage	Numeric criteria for appearance		
	Maximum crack width		Minimum crack distance
	Reinforced concrete (RC)	Prestressed concrete (PC)	
‘a’	No or hair crack		
‘b’	< 0.2 mm	< 0.1 mm	≥ 0.5 m
‘c’	< 0.2 mm	< 0.1 mm	< 0.5 m
	0.2 — 0.3 mm	0.1 — 0.2 mm	≥ 0.5 m
‘d’	0.2 — 0.3 mm	0.1 — 0.2 mm	< 0.5 m
	≥ 0.3 mm	≥ 0.2 mm	≥ 0.5m
‘e’	≥ 0.3 mm	≥ 0.2 mm	< 0.5 m

Steel corrosion

Extent of damage	Corroded depth	Corroded area
‘a’	No damage	
‘b’	Minor	Minor
‘c’	Minor	Major
‘d’	Major	Minor
‘e’	Major	Major

Corroded depth

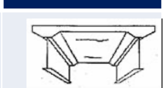
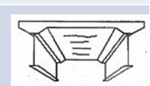
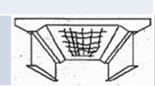
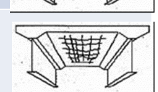
Minor	Decrease in plate thickness is negligible or rust has developed only on the plate surface
Major	Clear decrease in plate thickness is notable or the swelling of rust is visible.

Corroded area

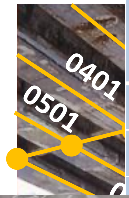
Minor	Rust areas are not widespread, and exist only locally
Major	Rust or several rust areas have spread over the DRs

RC deck cracking

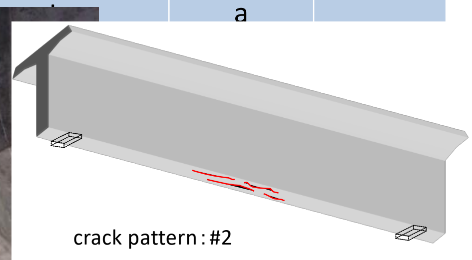
Combination of crack width, density, and direction

Extents	Numerical criteria for appearance			Examples
	Crack pattern	Crack spacings	Width of most cracks	
‘a’	One directional crack	1.0 m or larger	0.05 mm or narrower	
‘b’	One directional cracks are still prevailed	1.0 m to 0.5 m	Less than 0.1 mm	
‘c’	A two-directional crack pattern is developing but it has yet to be like a mesh	0.5 m and around	Less than 0.2 mm	
‘d’	A two-directional crack pattern is fully developed	0.5 m to 0.2 m	0.2 mm or more	
‘e’	A two-directional crack pattern is fully developed	Less than 0.2 m	0.2 mm or more & abrasion is well-developed continuously at the crack surface.	

Segmental data recording protocol

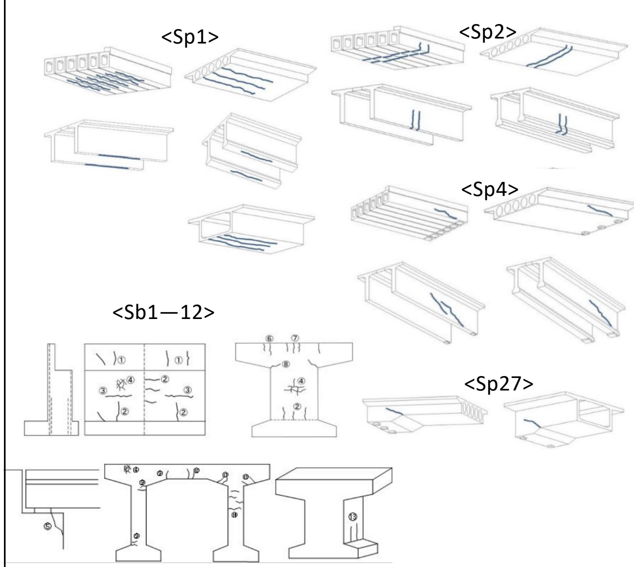


Categories of defect	Damage extent	pattern
#6 cracking	d	#2
#7 Water seepage / efflorescence	d	
[illegible]	a	

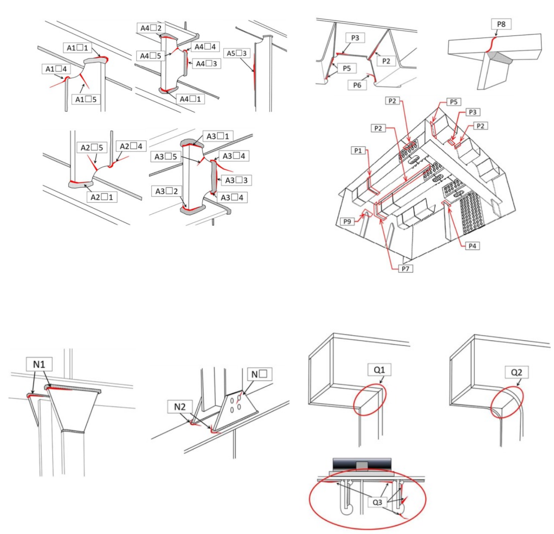


Cracking pattern classification IDs

Concrete



Steel



Markov transition probability matrices

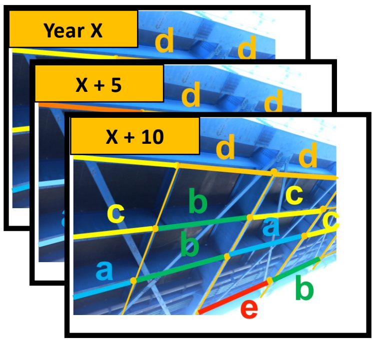
Element type

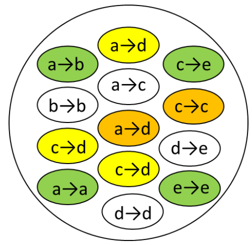
Damage type

Year X

Year X + 5

Year X + 10

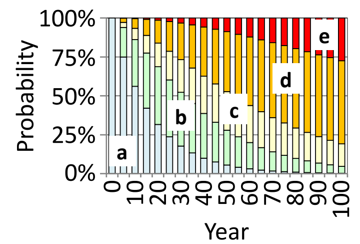




$$P = \begin{pmatrix} p_{aa} & p_{ab} & p_{ac} & p_{ad} & p_{ae} \\ 0 & p_{bb} & p_{bc} & p_{bd} & p_{be} \\ 0 & 0 & p_{cc} & p_{cd} & p_{ce} \\ 0 & 0 & 0 & p_{dd} & p_{de} \\ 0 & 0 & 0 & 0 & p_{ee} \end{pmatrix}$$

{Probabilities of `a'-`e' at year 5m}

$= \lfloor 1, 0, 0, 0, 0 \rfloor [P]^m$



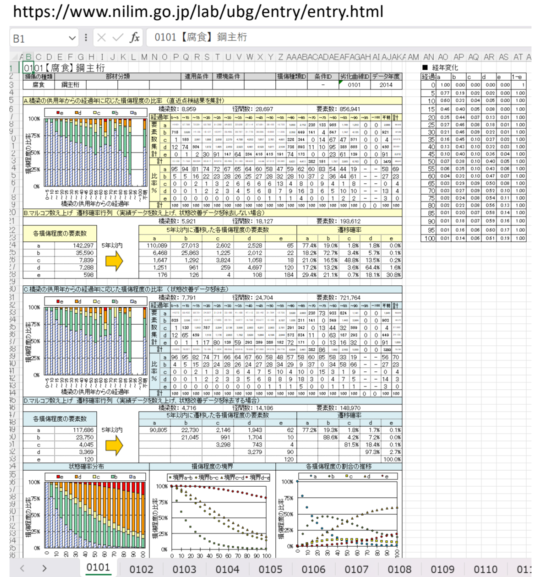
NILIM data analysis reports

- MS-Excel files are available online, which include more than 250 types of transition probability matrices and average deterioration curves for major structural elements with parameters of: for example,
  - materials,
  - design specifications
  - environmental conditions
  - segment locations --- span-ends VS span-centers, edge girders VS inside girders
- At least, bridge owners can compare the conditions of a particular bridge and its specific structural elements to the corresponding national average.

■ The cost of the data recording and storage is considerable.

■ To make this data recording practice sustainable, we need to continue demonstrating to bridge owners and users the additional benefits of detailed data recording.

https://www.nilim.go.jp/lab/ubg/entry/entry.html



Issues to maximize the benefit of the data recording

1. Can we develop a standardized LCC calculation protocol that all bridge owners can follow and adhere to?
2. Can we develop the use rule for the calculated performances and LCCs?
3. Some limitations may be necessary regarding the data usage in the investment priority analysis for bridges as part of asset management.
4. Data should also be used to dig into new recommendations and standards in bridge design and maintenance at the national level.?

Issue 1/5: Can we develop a standardized LCC calculation protocol that all bridge owners can follow and adhere to?

- We would like bridge owners to calculate the LCC for bridges so that the ministry can total their calculation results to estimate the national needs of investment in bridge preservation.
- However, many assumptions are made to calculate performance and LCCs.
  e.g.
  - Bridge conditions
  - Needs of repair
  - Remedial measures and areas, site work conditions, and costs
- Can we standardize what and how to be considered? Can we hold any consensus about the degree of possible error in the calculated LCC?
  - The amount and quality of data can differ among owners.
  - The number and type of assets can differ among owners.

Issue 2/5: Can we develop the use rule for the calculated performances and LCCs?

1. Calculated performance degradation and LCC based on the damage records are subject to significant uncertainties due to the assumptions underlying the calculation.
2. Symptom-based actions may theoretically reduce the calculated LCC.

■ Idea: To develop guidance on the cautious use of life cycle cost calculation results

- Both good and not-so-good implementations of LCC-based management

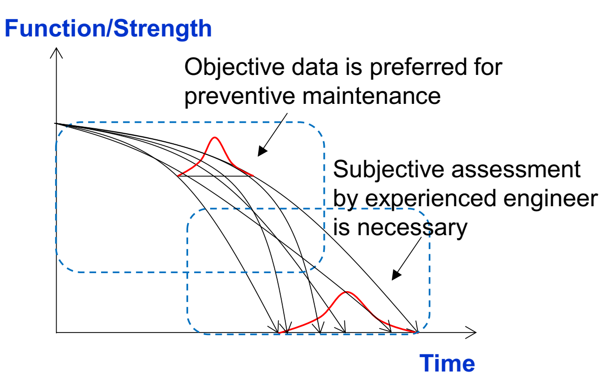


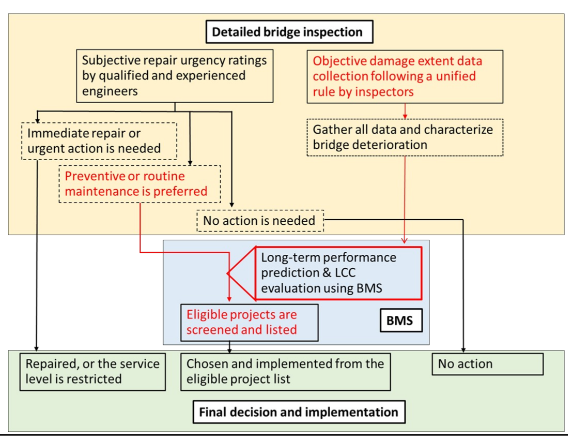

Issue 3/5: Some limitations may be necessary regarding the data usage in the investment priority analysis for bridges as part of asset management

❑ Is it fair to say that statistical analysis should be used to identify bridges that can be prioritized for preventive maintenance, rather than bridges that are likely to collapse?

❖ Failure = Sudden ---Not clear which one deviates first from the deterioration trend data.

❖ Data indicating a larger extent of damage is rare.





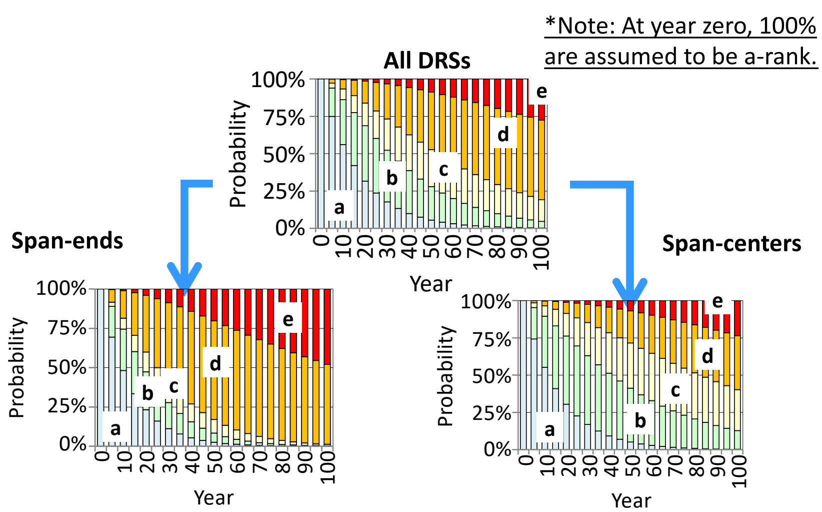
Issue 4/5: Data should also be used to dig into new recommendations and standards in bridge design and maintenance at the national level

- What can we do in data mining?
- Examples of data analyses ---verifying the empirical knowledge

Corrosion in steel girders

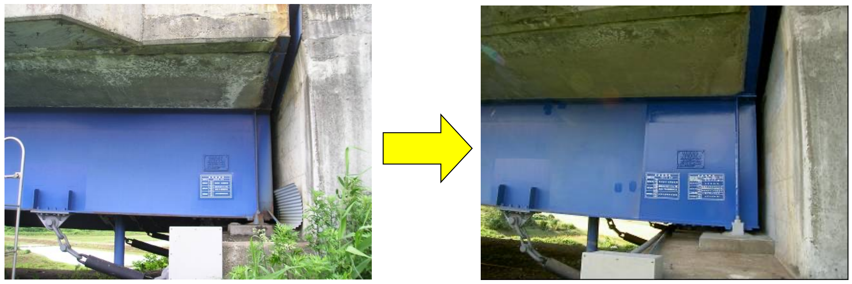
The segmental data is granular in terms of spatial detail within structural elements.

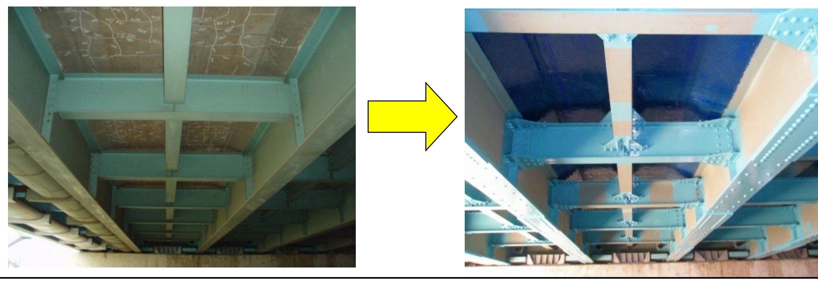
- Deterioration trends vary between span-ends and span-centers.
- At span-ends, the deterioration evolves very fast once it happens
- At span-centers, the state of corrosion changes gradually.



NILIM has proposed the draft zone painting specifications for saving LCC

Before the work **After the work**

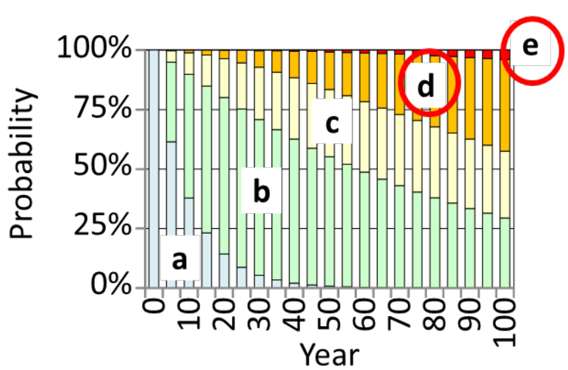




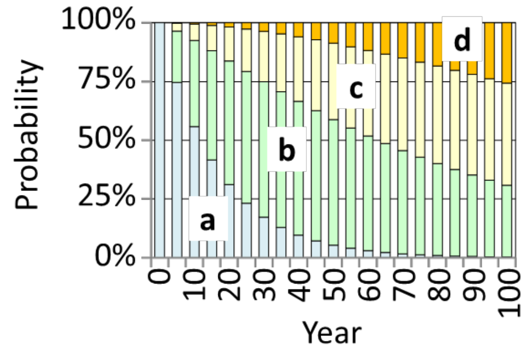
RC deck deterioration

Cross-data analysis for the influence of water

DRSs have efflorescence



DRSs have no efflorescence

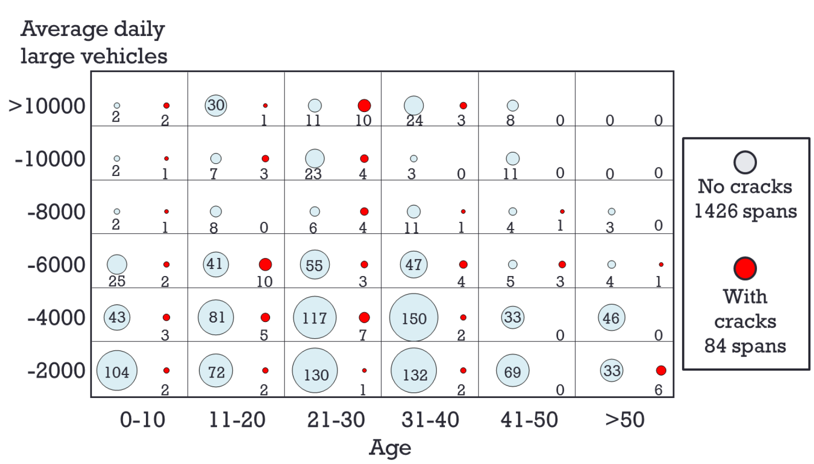


Deck waterproofing work became mandatory in 2002 in the bridge design specifications in Japan

Number of spans with cracks detected in steel deck plates by age and average daily heavy vehicle loads

- ❑ The development of cracks is not related to ADTT or the number of years.

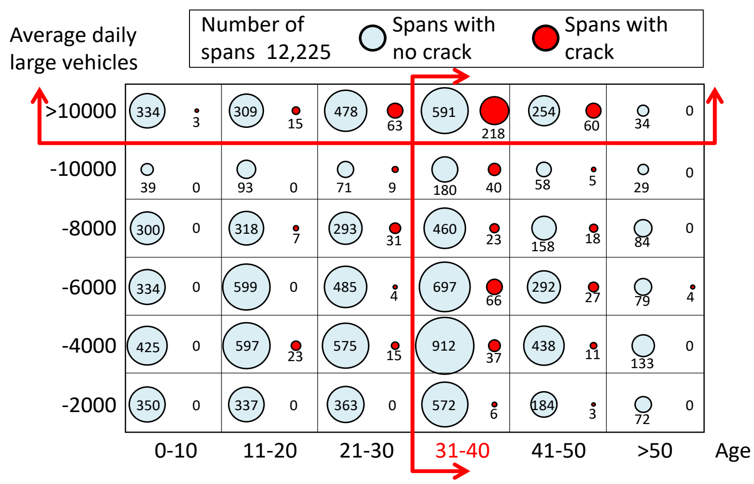
⇒ In 2009, the minimum deck plate thickness was raised to 16 mm from 12 mm.



Number of spans with cracks detected in steel girders by age and average daily heavy vehicle loads

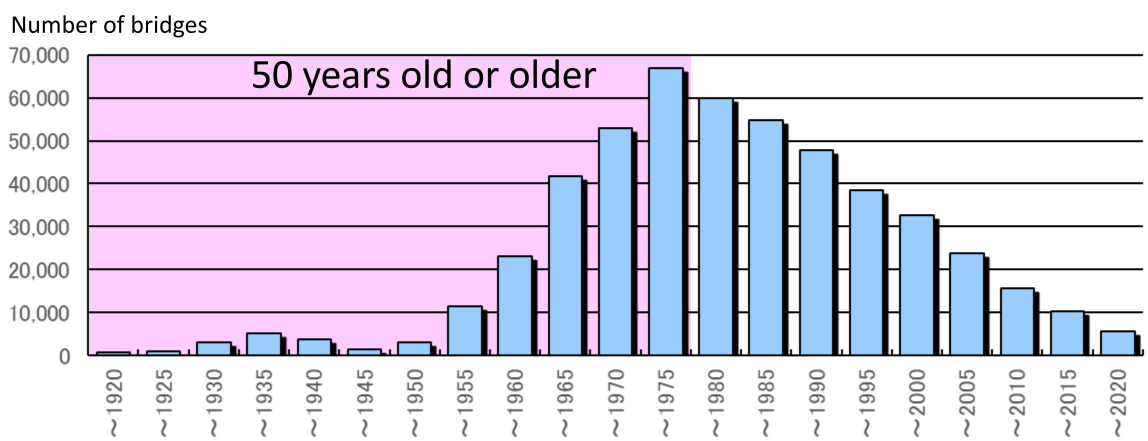
- Bridges become vulnerable to fatigue as they carry more trucks and get older.

→ Typical fatigue design is workable.



Aging: Number of road bridges by year of construction

- Bridges built in the historic economic growth years will become 50 years old and older.
- It is likely to increase in the need of bridge preservation and rehabilitation for years to come.



Note: There are additional 230,000 municipally-managed bridges with a length ranging from 2m to 15m which have no age data.

Bridge Load Rating

DEPARTMENT OF TRANSPORTATION

Ed Lutgen | MnDOT State Bridge Engineer

Rating Basics

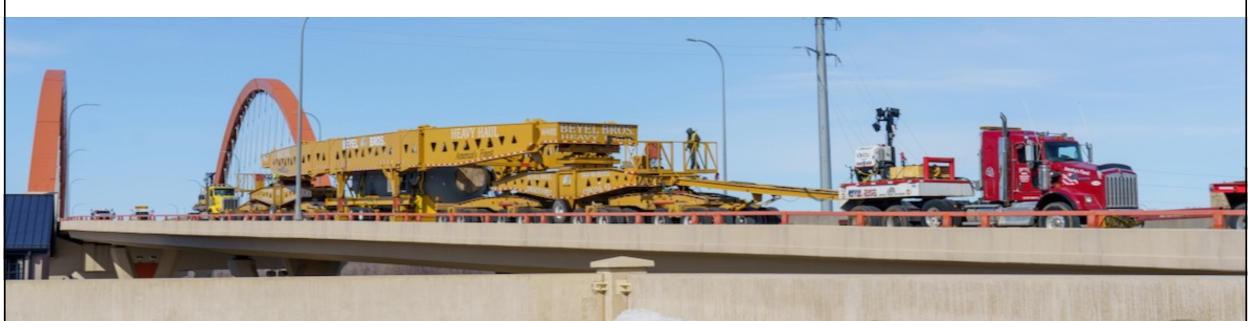
- $Rating\ Factor = \frac{(Capacity - Dead\ Load)}{Live\ Load}$
- Inventory Rating – Design level, unlimited cycles. Beta = 3.5
- Operating Rating – Maximum permissible load allowed on bridge. Limited cycles. Beta = 2.5
- Permit Rating – Oversize weight truck evaluation
- Legal Loads – National posting trucks or state specific trucks

Rating Times

- Load Rating when
  - New
  - Added dead load (overlay, heavier barrier)
  - Increase in legal load (posted?)
  - Change in specification (new research, code changes)
  - Deterioration of structural element
  - Rehabilitated or strengthened of critical elements
  - Bridge hit, flooding, substructure movement

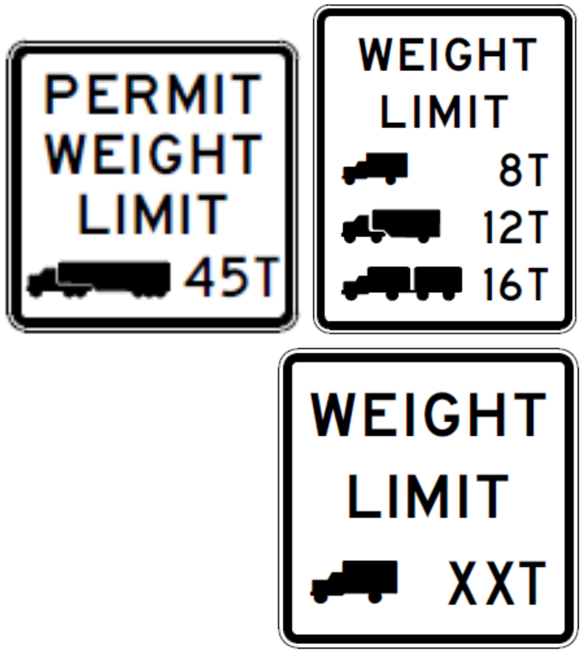
Above Legal Load Permitting

- Each state has own legal load limit. Permits are needed for evaluating routes safely
- MnDOT processed 150,000 permits in 2024
- Indivisible (can’t make two trips)
- Trunnions
- AASHTOWare BrRating software database



Bridge Posting

- AASHTO Posting Trucks
- State specific legislation
- Specialized Hauling Vehicles SHV
- Emergency Vehicles EV
- Permit Truck posting
- Implement of Husbandry



Posting Truck Pictures

Single Unit or Semi – 24 or 40 tons

Posting Truck Pictures

Implement of Husbandry - 50 tons +

Posting Truck Pictures

Emergency Vehicle – 30 ton Dual Axle

Posting Truck Pictures

Timber Hauler 99 kips

Posting Truck Pictures

SU7 Specialized Hauling Vehicle – 38 tons

Challenges

- Permit restrictions being followed by trucker (single lane, reduced speed)
- Evaluating long span bridges (same lane, adjacent lane)
- Changing Legal Load from state to state
- Design codes can become more conservative over time which reduces live load capacity for existing bridges (changing MBE and LRFD but not Standard Specs)
- Calculated ratings not representing current conditions (buried structures)
- Incorporating accurate deteriorated conditions
- Autonomous vehicles (probability assumptions)
- Local Agency (self performed inspections and load ratings)

DEPARTMENT OF TRANSPORTATION

Thank you again!

Edward Lutgen

Edward.Lutgen@state.mn.us

651-366-4507

1

Development of Repair and Rehabilitation Design Codes for Road Bridges

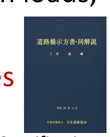
Eisuke NAKAMURA
Center for Advanced Engineering Structural Assessment and Research, PWRI

Masahiro SHIRATO
Bridge and Structures Division, NILIM, MLIT

2

Backgrounds

- In Japan, discussions have begun on developing design codes for the evaluation, repair, and rehabilitation of existing bridges.
- The latest revision of "*Specifications for Highway Bridges*" introduces updated design loads, revised design formulas and modified partial factors.
- Applying the current specifications to the repair and rehabilitation of existing bridges presents various challenges.


Specifications for Highway Bridges

Challenges in Repair and Rehabilitation of Existing Bridges

1. When existing bridges are assessed under the updated specifications, many are found to be non-compliant. However, most of these bridges exhibit no observable signs of structural damage in practice.
2. The applicability of verification formulas and resistance factors from the updated specifications to existing bridges remains uncertain.
3. When repair materials are introduced, it is challenging to evaluate how loads are shared between existing structures and repaired sections.
4. The extent of accumulated deterioration caused by factors such as fatigue and chloride ingress remains unclear.
5. Since existing bridges retain residual stress, even partial cross-sectional cutting during repair work may cause stress redistribution that diverges from analytical predictions and could introduce new structural weaknesses.

Existing Bridges

Repair & Rehabilitation

Objectives

- It is not reasonable to evaluate, repair and rehabilitate existing bridges using the same design specifications applied to new bridges.
- By establishing performance evaluation methods tailored to existing bridges, the design specifications for new bridges can be rationalized and optimized.

Objectives:

To exchange perspectives on the challenges and recent advancements in the development of the design codes for the repair and rehabilitation of existing bridges

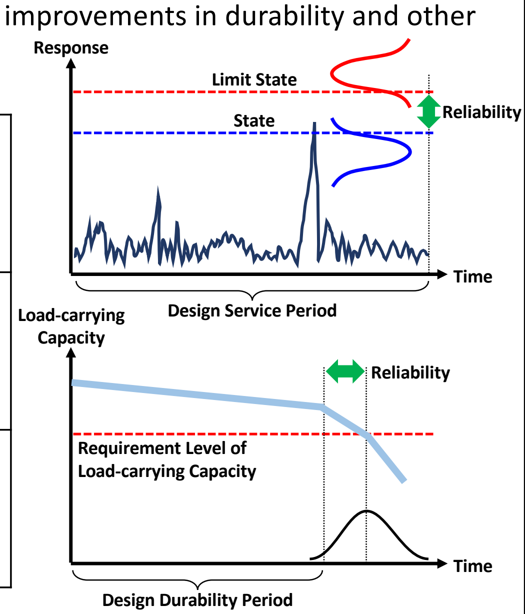
Topics to Cover:

1. Load-carrying performance: Design loads, load effects and structural resistance
2. Durability performance: Design durability period and life cycle cost

Performance of Bridge

- In Japan, the performance of a bridge is defined in terms of three key aspects: 1) load-carrying performance, 2) durability performance, and 3) functional performance based on the intended use.
- When evaluating existing bridges, the first step is to assess their load-carrying performance. Based on this assessment—and taking into account factors such as maintenance requirements—it is appropriate to consider potential improvements in durability and other performance aspects.

Load-carrying Performance	The performance required to ensure, with the necessary level of reliability, that the bridge remains within the expected condition category—based on its ability to support loads under the design situation and from the perspective of structural safety.
Durability Performance	The performance required to ensure, with the necessary level of reliability, that material deterioration over time does not affect the load-carrying performance of the bridge throughout its design service life.
Functional Performance Based on Intended Use	Maintainability, Inspectability, Recoverability The performances required to ensure that the bridge demonstrates the required structural and durability performance; however, they cannot be evaluated solely in terms of safety factors.



Load-carrying Performance

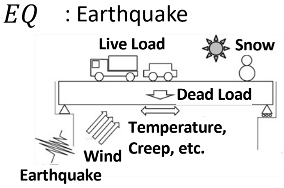
- In Japan, the load-carrying performance of a bridge is evaluated by verifying the performance of each individual bridge component, tanking into account three factors: 1) load, 2) load effects and 3) resistance.
- The load-carrying performance of components shall conform to the following formula.

$$\sum S_i\left(\gamma_{pi}\gamma_{qi}P_i\right) \leq \xi_1\xi_2\Phi_R R$$

Load

Examples of Load Types:

D : Dead Load
L : Live Load
CR : Creep
TH : Temperature Change
SW : Snow Load
WL : Wind Load
EQ : Earthquake



Note: There are twenty types of loads.

Load Effects

S_i : **Load effect**
P_i : Load
γ_{pi} : Load combination factor
γ_{qi} : Load factor

Examples of Load Combination:

1.05 D + 1.25 L
1.05 D + 0.95*1.25 L + 0.75 TH
1.05 D + 0.50 TH + 0.5 EQ
1.05 D + 1.25 W

Note: There are twelve types of load combinations.

Resistance

R : **Resistance**

Φ_R : Resistance factor that consider the model uncertainty in estimating R and the variabilities of material properties under the condition where the variability in construction quality is equal to that of the earlier practice

ξ_1 : modifier for unavoidable uncertainty in modeling the boundary conditions and investigation (= 0.90)

ξ_2 : modifier for the consequence of failure (= 0.85 to 1.00)

Challenges

- In evaluating the load-carrying performance of existing bridges, it is necessary to examine how to define the load, load effects and resistance.

Load

- There is room to reconsider the reference period used for setting load factors.
- However, since the live load factor is set at 1.25, revising the reference period to determine the live load factor may only have a limited effect.

Load Effects

- For existing bridges, it is uncertain whether the load path and load-bearing members are consistent with those in the original design.
- How should we use measurement results, such as sectional force and stress, for assessing load-carrying capacity of existing bridges?
- These measurement results reflect load distributions into unintended structural members, rather than being concentrated solely in the originally designed load-bearing members.

Resistance

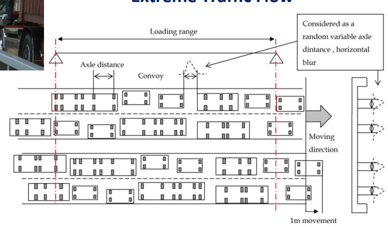
- The majority of the safety margin, typically between 1.7 and 3.0 in allowable stress design, has been intentionally allocated to the resistance side.
- This design allows for adjustment to resistance factors and modifiers to be made during the evaluation of existing bridges, assuming resistance can be accurately assessed.
- We aim to apply this approach to facilitate more reliable and appropriate evaluation of existing bridges.

Case Study: Load Factor

- Large-scale probabilistic simulations were conducted on several bridges, varying the reference period to determine the live load factor.
- The results indicated that changes in the reference period have minimal impact on the live load factors. In cases where the expected design service period is approximately 10 years, there is potential to reduce the live load factors.

Simulation for Live Load Factor

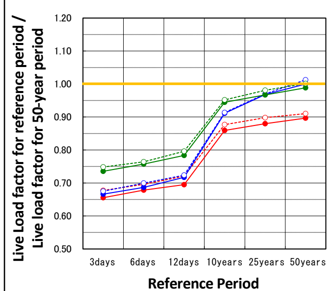
Extreme Traffic Flow



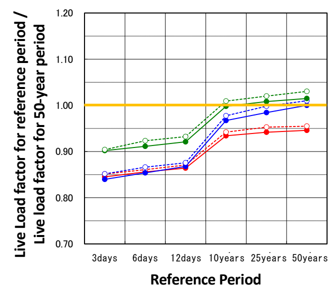
- In Japan, the maximum live load effects are assessed using extreme traffic flow.
- The live load factor is determined based on the maximum cross-sectional force distributions observed in the superstructures of sample bridges.

Example of Simulation Results
(Live Load Factor over Reference Periods)

Steel simply-supported non-composite plate girder (Span length = 18.3m)



Prestressed concrete continuous composite girder (Span length = 35.2m)



Data Provided by Bridge and Structures Division, NILIM

Note: Simulation results for three traffic flow types with varying rates of heavy vehicle inclusion

- In cases where the expected design service period is approximately 10 years, there is potential to reduce the live load factors.
- The load factors associated with temperature and wind exhibit little variation with changes in the reference period.

Case Study: Resistance Factor and Modifier

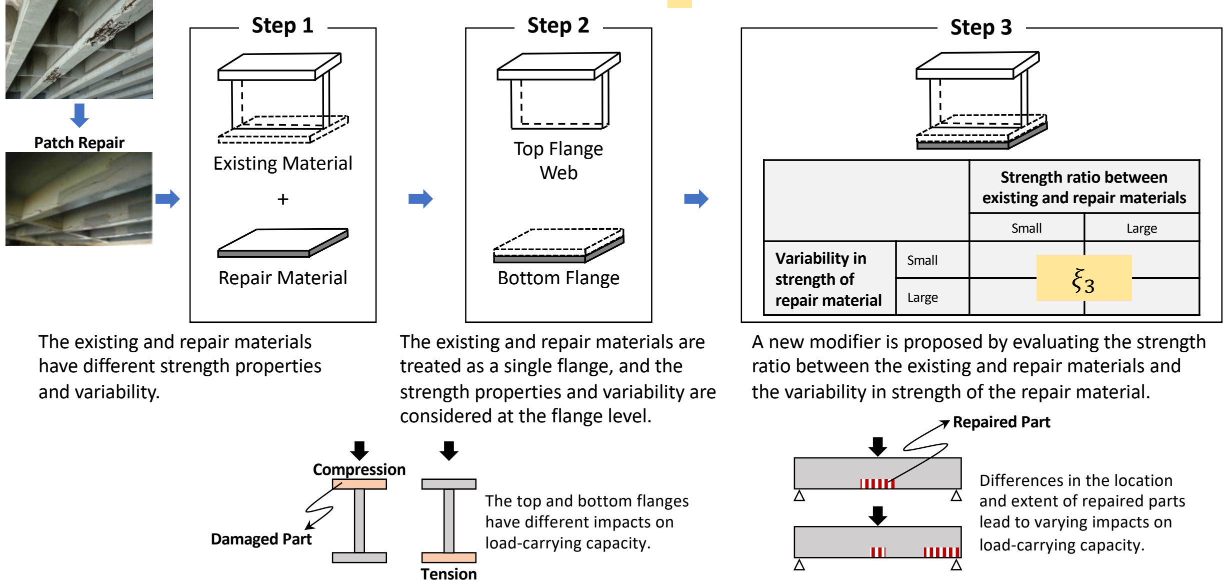
- The following challenges have been identified in evaluating resistance factors and modifiers for new bridges and for existing bridges, respectively.

	New Bridge	Existing Bridge
Resistance Factor Φ_R	• Variability in material properties and fabrication errors should be considered during the design process. • The resistance factors are calibrated based on conventional design specifications to minimize significant changes.	• Variability in material properties or fabrication errors does not necessarily need to be considered during the design process. • There is a possibility that the resistance factor may be set closer to 1.00.
Modifier $\xi_1\xi_2$	• New bridges are generally assumed to be unaffected by deterioration mechanisms, such as fatigue and chloride ingress. • The material properties and structural details are in compliance with the current specifications.	• The stress and deterioration conditions of existing bridges are not clearly understood. • Material properties and structural details may differ from the current specifications, and there is uncertainty in applying the load-carrying capacity formulas and resistance factors. • Variability in material properties and uncertainties in design and construction quality remain issues in repair work. • There is a possibility that the modifier may be difficult to revise.

Case Study: New Modifier

- Since various materials are employed in the repair design of existing bridges, establishing a comprehensive rule for adjusting the resistance factor is expected to facilitate evaluation.
- To address the variability in repair material properties and methods, a new modifier is currently under consideration.

$$\sum S_i \left(\gamma_{pi}\gamma_{qi}P_i\right) \leq \xi_1\xi_2\xi_3\Phi_R R$$



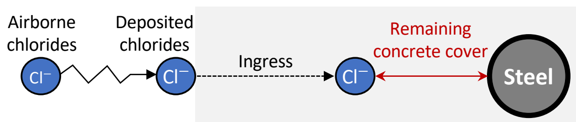
Key Issues

	Japan's Perspectives	Questions?
Load	• In Japan, in order to achieve nationwide consistency in traffic management, there is no plans to change the characteristic values of live loads and the load factors used to evaluate the load-carrying performance of existing bridges.	• In the United States, what challenges have been identified in establishing load factors for evaluating the load-carrying performance of existing bridges? • What types of research are currently underway?
Load Effects		• In the United States, are there established standards for conducting load tests to determine sectional force distributions in existing bridges? • Are road administrators allowed to independently derive design loads from Weigh-In-Motion (WIM) data?"
Resistance	• In Japan, several research projects are underway to establish resistance factors for evaluating the load-carrying capacity of existing bridges.	• In the United States, are there any examples of research being conducted on evaluating the load-carrying capacity of existing bridges and the associated resistance factors? • What practical challenges are recognized in evaluating the load-carrying capacity of existing bridges before and after repair?

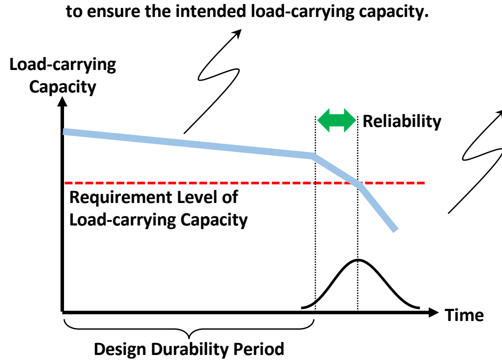
Durability Performance

- In Japan, the durability performance of existing bridges and their components is evaluated based on the design durability period.
- The period refers to the time during which the structural cross section is expected to maintain its integrity, ensuring the intended load-carrying capacity and serving as the basis for assessing cumulative load effects.
- For new bridges, a design durability period of 100 years is commonly adopted.

Example of Chloride-induced Corrosion



The structural cross section maintains its integrity to ensure the intended load-carrying capacity.



The load-carrying capacity is reduced due to cross-sectional loss caused by chloride-induced corrosion of reinforcement.

Verification Formula

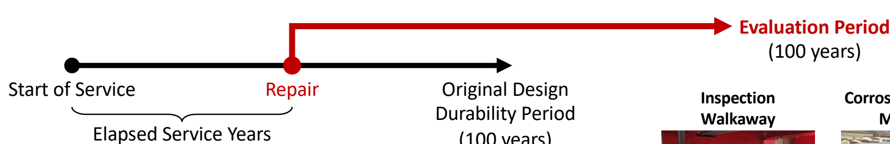
Cumulative Load Effect < Limit Value of Cumulative Load Effect Maintaining Cross Section Integrity

Design Durability Period and Life Cycle Cost

- The design durability period represents the timeframe during which the load-carrying capacity of bridge components is expected to remain unaffected, assuming that appropriate maintenance is carried out as planned and component replacement is feasible.
- It also serves as the evaluation horizon for life cycle cost analysis, which includes inspection and maintenance expenses required to ensure the durability performance of bridge components.

- In the repair design of existing bridges, one of the challenges is determining the evaluation period for life cycle cost analysis when selecting the repair strategy and method.
- In Japan, the evaluation period is expected to be set 100 years.

Challenges in Setting Appropriate Evaluation Period



- When the evaluation period for life cycle cost analysis is long, there is a strong incentive to adopt structural configurations for easier inspection and to employ materials for enhanced durability.
- **However, when the period is short, such incentive tends to diminish.**

Key Issues

	Japan's Perspectives	Questions?
Evaluation Period for Life Cycle Cost Analysis	• In Japan, the evaluation period for life cycle cost analysis during repair design is expected to be set at 100 years. • The design durability period refers to the expected duration determined at the time of repair design, rather than the number of years the existing bridge has already been in use. • If a bridge replacement has already been scheduled, the planned replacement day may be used as the maximum value for the design durability period.	• In the United States, how is the evaluation period for life cycle cost analysis determined during repair design? • Are there any incentives to apply structural configurations for easier inspection or to employ materials for enhanced durability by setting a longer evaluation period? • In the context of repair design, is it appropriate to conduct a survey to assess the remaining design durability period?

Summary

- In Japan, discussions have begun on developing design codes for evaluating, repairing, and rehabilitating existing bridges.
- In evaluating the load-carrying performance of existing bridges, it is necessary to examine how to determine the load, load effects and resistance.
- In the repair design of existing bridges, one of the challenges is determining the evaluation period for life cycle cost analysis when selecting the repair strategy and method.

New Jersey Department of Transportation

Risk Assessment for New Jersey Bridges

33rd U.S. – Japan Bridge Workshop

August 4, 2025

By

Harjit S. Bal, P.E.

Supervising Engineer Structural Evaluation

NJDOT Bureau of Structural Evaluation and Bridge Management

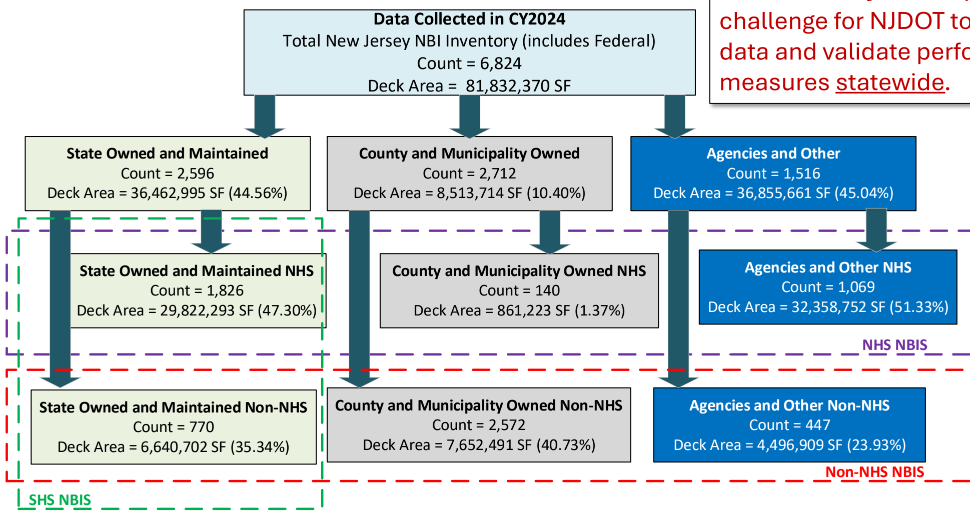
New Jersey Facts

NBIS Bridges	Count
State maintained NBIS (more than 20ft length) bridges	2,596
County/Municipality owned NBIS bridges	2,712
Toll agency owned NBIS bridges	1,333
NJ Transit owned NBIS bridges	104
Other agency and Private NBIS bridges	49
Federally owned NBIS bridges	30
Total	**6,824**

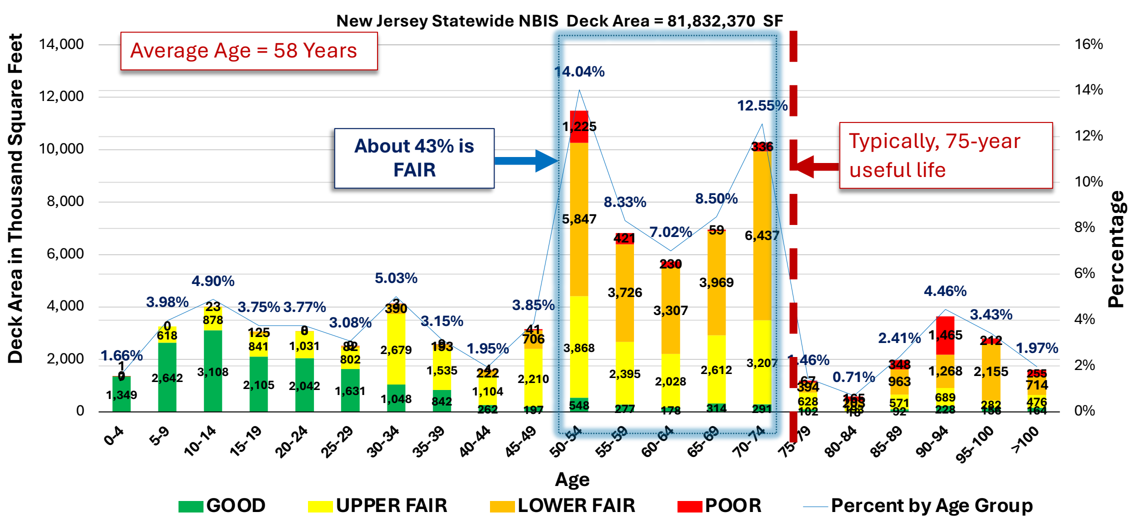
Other Structures	Count
State owned minor (5ft to 20ft) bridges	953
County/Municipality owned minor bridges	5,200
State owned NTIS tunnels	1
Toll agency owned NTIS tunnels	4
State owned OHSS	1,892
State owned HMLP	244
State owned pedestrian bridges	72
State owned dams	28
Total	**8,394**

New Jersey Facts

There are **96 DISCRETE OWNERS in New Jersey**, which poses a challenge for NJDOT to manage data and validate performance measures statewide.



New Jersey Facts



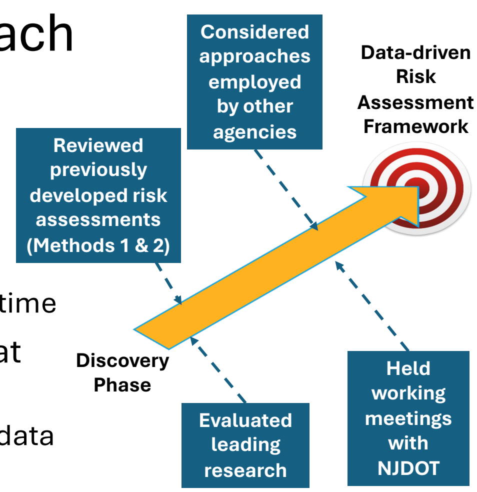
New Jersey Facts

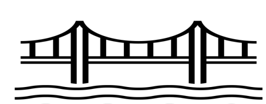
- **With the aging bridge infrastructure in New Jersey, there is a daunting challenge for NJDOT to create <u>data-driven</u> risk-based predictive models and deterioration trends to inform investment decisions for bridge replacement, rehabilitation, and preservation programs at an <u>optimal cost</u>.**

- **As our bridges continue to age, Risk Assessment Management is an important aspect of Bridge Asset Management**

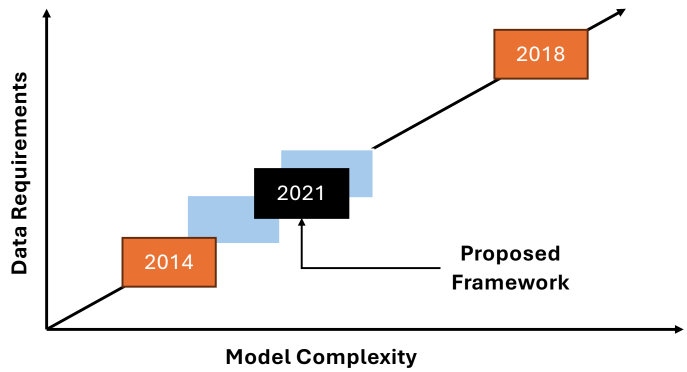
New Jersey DOT Risk Approach

- Develop a data-driven **risk assessment**
  - To provide a risk score at **asset level**
  - To make informed investment decisions
  - To provide network-wide prioritization
  - To clearly communicate risk priorities over time
- Initial goal: Create a **simple process** that
  - Can be **readily implementable**
  - Utilize National Bridge Inventory and State data
  - Support decision making directly
  - Standalone Microsoft Excel tool





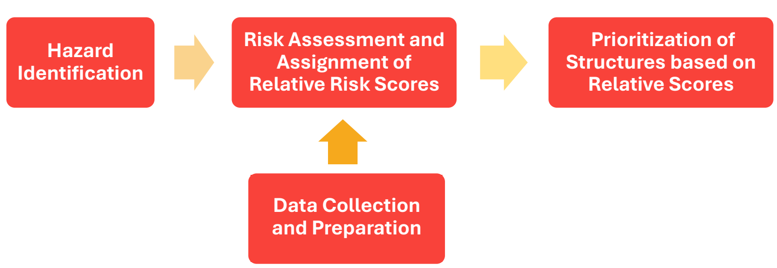
New Jersey DOT Risk Framework



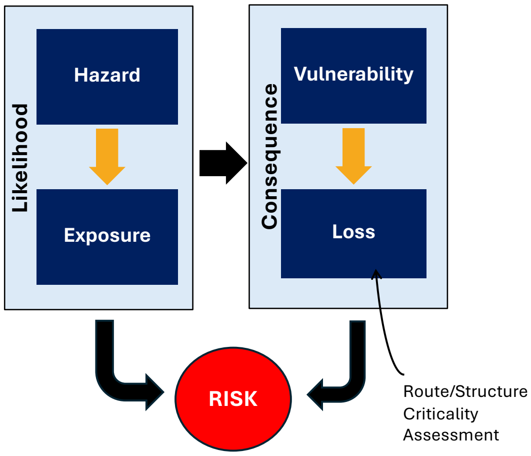
- **2014**:
  - Initiated Risk – Academia
- **2018**:
  - Probabilistic methodology – Academia
- **2021**:
  - Hybrid model (NJDOT Adopted) – Consultant
- **2024-2025**:
  - Validation of Adopted model – Consultant
  - Enhancement to new 2024 Specifications for the National Bridge Inventory (SNBI) – Consultant

New Jersey DOT Risk Framework

- **Hazard Identification**:
  - Threats (risks) that might affect the safety and serviceability of NJDOT's structures.
  - Eight hazards - "***8 Risk Categories***"
    - plus "***2 new bridge fire and bridge security***"
  - Each risk category assessed *independently*



New Jersey DOT Risk Framework

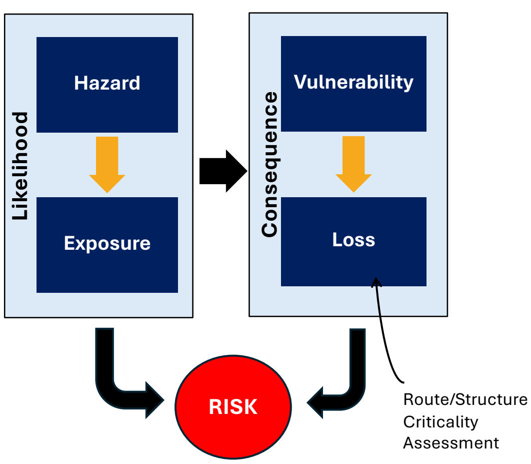


- **Hazards** arise from a variety of geological, meteorological, hydrological, oceanic, and physical conditions, human actions, and generated causes, sometimes acting in combination.
- **Exposure** refers to the demand created externally or internally that the structure needs to withstand.
- **Vulnerability** captures the capacity to meet the demand created by exposure. Factors - design capacity, susceptibilities, fragilities, and deficiencies affecting the structure's ability to withstand an event.
- **Loss** captures the expected asset owner and user consequences during or after an event. A route/structure criticality is used to evaluate user consequences of an event and loss in service.

Note:

The risk assessments terminology in the U.S. is not settled and that some other risk assessments may use these terms differently than we do in the NJDOT framework.

New Jersey DOT Risk Framework



- **Proposed approach** assigns a risk score to structures based on semi-quantitative approach
- **Risk** is defined as the aggregation of the likelihood of occurrence and consequence of an event occurring.
- **Failure modes** are possible ways in which the functionality or performance of the asset can be degraded or disrupted.

Risk Category	Failure Mode
Fatigue	Steel Fatigue
Flood	Superstructure Damage & Uplift

Risk Category	ailure Mode	Likelihood		
		Hazard	Exposure	
			Mitigation Strategy	Factors Affecting Demand
Fatigue	Steel Fatigue	Lifetime Loading		Bridge Design System Stiffness - Horizontal Curved Girder - Skew Index - Superstructure Flared Bearing Type
Flood	Superstructure Damage & Uplift	Flood Plain		Waterway Adequacy - Deck Parapet/Bridge Railing Located over a Navigable Waterway
Scour	Substructure Failure	Flood Plain	Scour Countermeasure & Condition Channel & Channel Protection Condition	Scour Criticality
Overload	Structural failure due to Truck Traffic	Average Dailly Truck Traffic (ADTT)		
Seismic	Structural failure due to earthquake activity	Location of Bridge PGA (Peak Ground Acceleration) Coefficient		Location of bridge - North, Central or Southern regions (soil type/site conditions)
Vehicle Sub Collision	Structural failure due to collision with substructure	ADTT (under roadway) Corridor Speed		Underpassing Roadway Configuration
Vehicle Super Collision	Structural failure due to collision with superstructure	ADTT (under roadway) Corridor Speed	Warning signs (underclearances) and enforcement	Minimum Vertical Clearance (feet) History of collision hits/scrapes
Vessel Collision	Structural failure due to collision with vessel	Marine Traffic	Bridge Protective Systems Protection System Condition/Adequacy	Navigation Clearances

Risk Category	Failure Mode	Consequence	
		Vulnerability	Loss
Fatigue	Steel Fatigue	Superstructure Condition, Fatigue Details, Superstructure Redundancy (Load Path only)	Structure Replacement Cost
Flood	Superstructure Damage & Uplift	Deck Type, Deck Condition, Bearing Type (Transverse Resistance), Superstructure & Deck Weight (Uplift Resistance), Superstructure Redundancy (Load Path & Structural), Superstructure Condition	Structure Replacement Cost
Scour	Substructure Failure	Substructure Condition, Superstructure Redundancy (structural only), Type of Foundation, Substructure Type/Redundancy, Existing Substructure/Scour Problems, Approach Roadway Embankment Condition	Structure Replacement Cost
Overload	Superstructure Damage & Uplift	LFR Operating rating, Superstructure Redundancy, Superstructure Condition	Structure Replacement Cost
Seismic	Substructure Failure	Bearing Type & Skew, Superstructure Redundancy (Load Path & Structural), Substructure Redundancy, Seismic Design Considerations by Year of Construction/ Rehabilitation	Structure Replacement Cost
Vehicle Sub Collision	Structural failure due to Truck Traffic	Substructure Condition, Superstructure Structural Redundancy, Substructure Redundancy, Substructure Material	Structure Replacement Cost
Vehicle Super Collision	Structural failure due to earthquake activity	Superstructure Condition, Superstructure redundancy (Load Path and Structural)	Structure Replacement Cost
Vessel Collision	Structural failure due to collision with substructure	Substructure Condition, Substructure Redundancy, Substructure Material, Superstructure Structural Redundancy	Structure Replacement Cost

New Jersey DOT Risk Framework Methodology

Fatigue Risk

HAZARD	EXPOSURE Demand exerted on the Structure	VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand	LOSS Agency Cost to Replace the Structure

Criteria scores range between 1 and 5.   5 is highest likelihood/loss.

*Only bridges with **steel** superstructures are scored for fatigue risk.*

*Fatigue in steel bridges refers to the **gradual weakening and potential failure** of steel components due to the repeated application of stress, even if those stresses are below the material's yield strength.*

New Jersey DOT Risk Framework Criteria

Fatigue Risk

HAZARD	EXPOSURE Demand exerted on the Structure	VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand	LOSS Agency Cost to Replace the Structure
Lifetime Loading			
Annual Average Daily Truck Traffic			
Superstructure Age			

New Jersey DOT Risk Framework Criteria

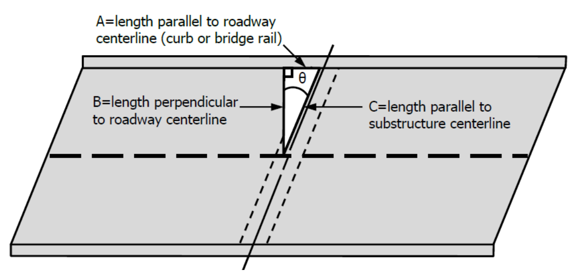
Fatigue Risk

HAZARD	EXPOSURE Demand exerted on the Structure	VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand	LOSS Agency Cost to Replace the Structure
Lifetime Loading	Bridge Design Practices and Quality Control		
Annual Average Daily Truck Traffic	System Stiffness - Skew		
Superstructure Age	Bearing Type		

New Jersey DOT Risk Framework Criteria

Fatigue Risk

EXPOSURE Demand exerted on the Structure
Bridge Design Practices and Quality Control
System Stiffness - Skew
Bearing Type



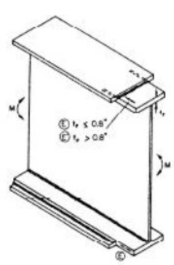
New Jersey DOT Risk Framework Criteria

Fatigue Risk

HAZARD	EXPOSURE Demand exerted on the Structure	VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand	LOSS Agency Cost to Replace the Structure
Lifetime Loading	Bridge Design Practices and Quality Control	Superstructure Condition	
Annual Average Daily Truck Traffic	System Stiffness - Skew	Fatigue Details	
Superstructure Age	Bearing Type	Load Path Redundancy	

New Jersey DOT Risk Framework Criteria

Fatigue Risk



☑ Detail 9

Cover Plates Wider than the Girder Flange with End Welds Category E or E'

VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand
Superstructure Condition
Fatigue Details
Load Path Redundancy

New Jersey DOT Risk Framework Criteria

Fatigue Risk

HAZARD	EXPOSURE Demand exerted on the Structure	VULNERABILITY Ability to resist the demand/ Likelihood of failure if exposed to the demand	LOSS Agency Cost to Replace the Structure
Lifetime Loading	Bridge Design Practices and Quality Control	Superstructure Condition	Deck Area
Annual Average Daily Truck Traffic	System Stiffness - Skew	Fatigue Details	
Superstructure Age	Bearing Type	Load Path Redundancy	

New Jersey DOT Risk Framework

Fatigue Risk – Example Bridge

Str. Num: 0916150

Name: NJ 495 EB AND RAMPS B & J / NJ 3 EB & US 1 RAMP

Type: Four Span, Simply Supported, Composite, Rolled Steel Multi-Girders with Three NSTM (**FCM**) Steel I-Beam Pier Cap.

Year Built: 1951
Deck = Severe
Super = Poor
Sub = Fair

Hazard – Lifetime Loading	Value	Risk Score
Superstructure Age (50%)	74 years	3.0
Average Annual Daily Truck Traffic (50%)	1,569 trucks per day per lane	3.1
Hazard Score		**3.0**

New Jersey DOT Risk Framework

Fatigue Risk – Example Bridge

SN 0916150 - NJ495 Ramp

Exposure	Value	Risk Score
Bridge Design Practices and Quality Control (30%)	1951 Construction Year	5.0
System Stiffness – Skew (50%)	39 degrees skew angle	5.0
Bearing Type (20%)	Rocker Bearings in Condition State 3 (poor)	4.0
Exposure Score		**4.8**

New Jersey DOT Risk Framework

Fatigue Risk – Example Bridge

SN 0916150 - NJ495 Ramp

Vulnerability	Value	Risk Score
Superstructure Condition (15%)	4 (Poor) (Range is 0 to 9)	4.0
Fatigue Details (50%)	E' Cover Plate Detail at I-Girder	5.0
Load Path Redundancy (35%)	Non-redundant Construction (Fracture Critical)	5.0
Vulnerability Score		**4.9**

New Jersey DOT Risk Framework

Fatigue Risk – Example Bridge

SN 0916150 - NJ495 Ramp

Loss	Value	Risk Score
Deck Area (100%)	20,820 square feet	1.2
Loss Score		**1.2**

New Jersey DOT Risk Framework

Fatigue Risk – Example Bridge

SN 0916150 - NJ495 Ramp

HAZARD	3.0
EXPOSURE	4.8
VULNERABILITY	4.9
LOSS	1.2
Fatigue Risk Score	$(3.0 * 4.8)^{\frac{1}{2}} X (4.9 * 1.2)^{\frac{1}{2}}$ $= 3.8 X 2.4$ = 9.1

New Jersey DOT Risk Framework Example

Fatigue Risk Score Sample Calculation

Hazard	Exposure			Vulnerability	Loss
	Filters	Exposure Mitigation Strategy	Factors Affecting Demand		
• Lifetime Loading (100%)	• Bridge Material	• N/A	• Bridge Design (20%) • System Stiffness (40%) - Horizontal Curved Girder - Skew - Superstructure Flared • Bearing Type (40%)	• Superstructure Condition (15%) • Fatigue Details (50%) • Superstructure Redundancy (Load Path only) (35%)	• Deck Area (100%)

Note that all current criteria weighting is proposed and subject to review and revision by NJDOT.

New Jersey DOT Risk Framework

- Questions?
- End of Presentation

Seismic Retrofit

Washington State's Program

Evan Grimm, State Bridge & Structures Engineer

August 4, 2025

Retrofit Techniques – Superstructure

Seismic Restrainers

Girder Stops

Catcher Blocks

Retrofit Techniques – Column Jacket

Jacket Before Install

Welding Jacket

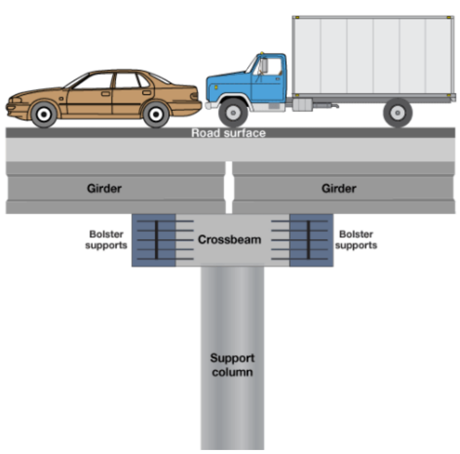
After Install

Finished Product

WSDOT

Retrofit Techniques – Crossbeam Bolsters

Multiple Column Retrofit



WSDOT

Seismic Retrofit Design Standards

- FHWA-HRT-06-032 Seismic Retrofitting Manual for Highway Structures: Part 1 – Bridges
- Amended by WSDOT Bridge Design Manual
  - Use current spectral response parameters
  - Seismic isolation requires special approval
  - Determine joint shear capacities using Caltrans Bridge Design Aid 14-4 Joint Shear Modeling Guidelines for Existing Structures

FRICTION PENDULUM BEARING

SR99 Aurora Ave Bridge in Seattle

WSDOT Seismic Retrofit Program

Objectives

- Prevent structural collapse.
- Prioritize projects to minimize loss of life/commerce.
- Accept moderate damage.
- Perform lower-cost work first.

WSDOT Seismic Retrofit Program

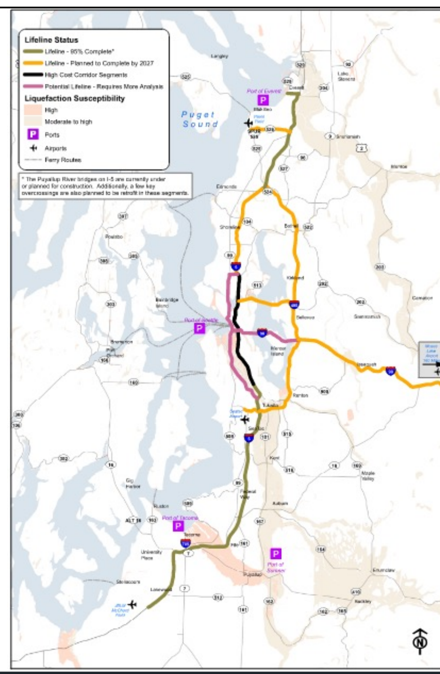
Phase 1: Simply supported bridges and bridges with in-span hinges

Phase 2: Major bridges and bridges with single column supports

Phase 3: Bridges with multiple columns

Seismic Lifeline

- Essential State Highways
- Largest Ground Motions
- High Population
- Reduce Risk
- Retrofit Existing
- New Bridge Design



WSDOT Seismic Retrofit Program

Spent to date	>$100M
Bridges Identified	923
Bridges Completely Retrofitted	333
Bridges Still Needing Complete Retrofit	463
Have Been Partially Retrofitted	127

WSDOT Seismic Retrofit Program

Limitations

- Minimizes but does not eliminate damage
- Above-foundation only
- No liquefaction
- Does not guarantee full post-EQ operation
- Emergency repairs may be needed for emergency vehicles
- Limited budget – cost/benefit

Liquefaction Example
2001 Nisqually Earthquake

US-Japan Bridge Workshop

History of disaster mitigation and prevention programs and development of risk management

Tomohiro NINOMIYA
Public Works Research Institute

Table of Contents

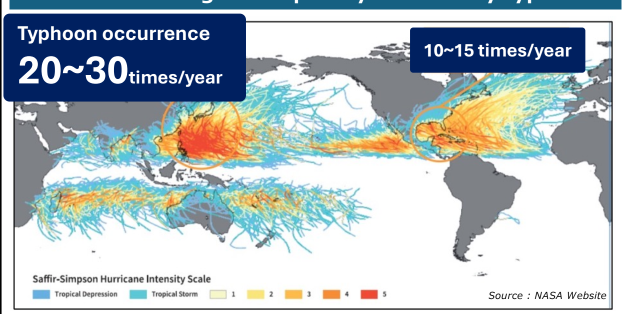
1. Characteristics of the Natural Environment Surrounding Japan's Social Infrastructure and an Overview of Recent Disasters
2. Plans and Budget Measures for National Resilience
3. Disaster Mitigation Measures and Risk Management
   - ・Disaster prevention inspection
   - ・Road Risk Assessment
   - ・Formulation of Road Clearing Plans
   - ・Emergency Inspections and Actions

Table of Contents

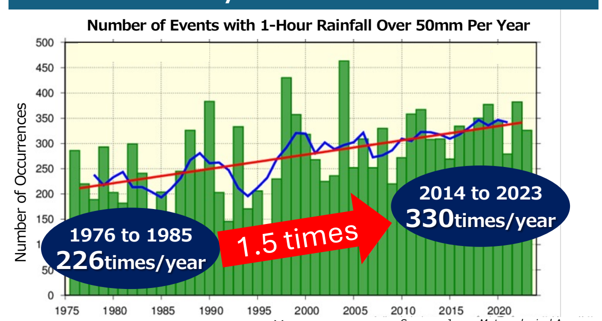
1．Characteristics of the Natural Environment Surrounding Japan's Social Infrastructure and an Overview of Recent Disasters

■ Compared to other countries, Japan has many steep mountain ranges and is situated under vulnerable geographical conditions, frequently experiencing natural disasters such as earthquakes, typhoons, and heavy rainfall

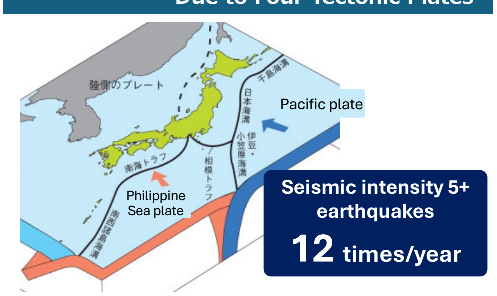
✓Located in a region frequently affected by typhoons



✓Increase in Heavy Rain Incidents



✓ Frequent Earthquakes Due to Four Tectonic Plates

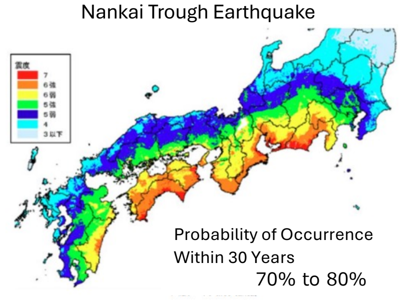


Source : JMA ,Monthly Earthquake Counts by Max Seismic Intensity (2014–2023)

✓Huge Earthquake Approaching

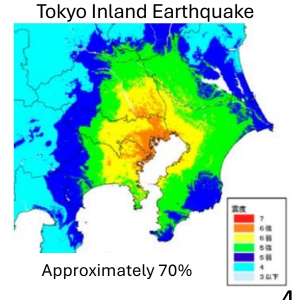
Seismic Intensity Distribution Maps

Nankai Trough Earthquake



Source: Central Disaster Management Council, Final Report on Tokyo Metropolitan Inland Earthquake Countermeasures

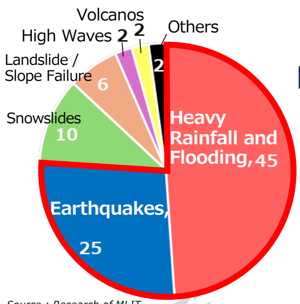
Tokyo Inland Earthquake



Source: Central Disaster Management Council, Final Report on Nankai Trough Megaquake Countermeasures

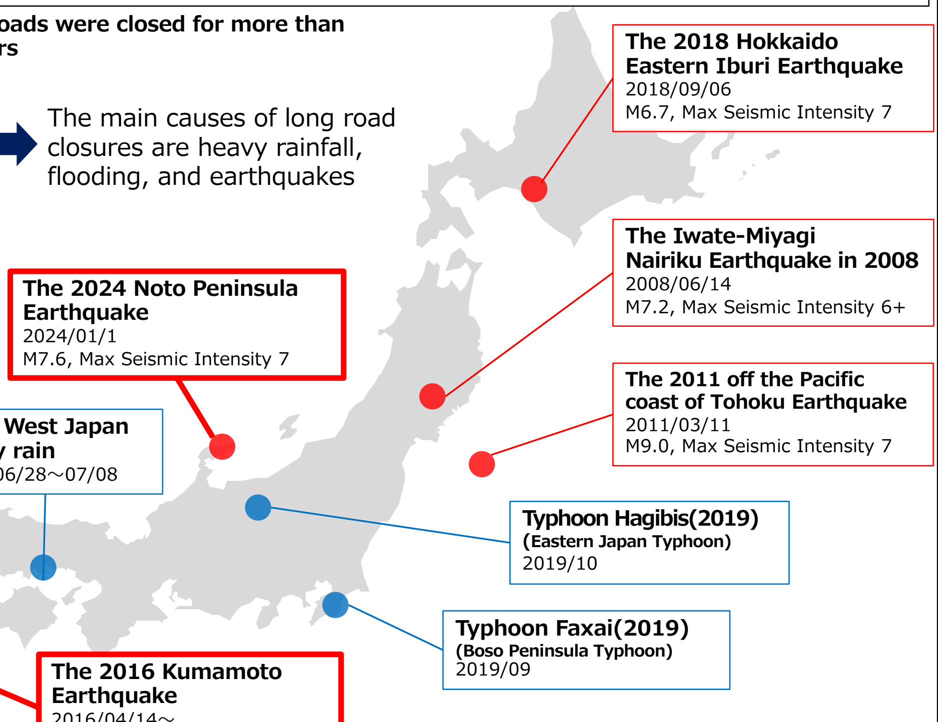
■In recent years, natural disasters such as earthquakes, heavy rainfall, and typhoons have been occurring frequently across the country, almost every year.

□ **Factors in cases where roads were closed for more than one week due to disasters**



Source : Research of MLIT

➡ The main causes of long road closures are heavy rainfall, flooding, and earthquakes



Source : Japan Meteorological Agency

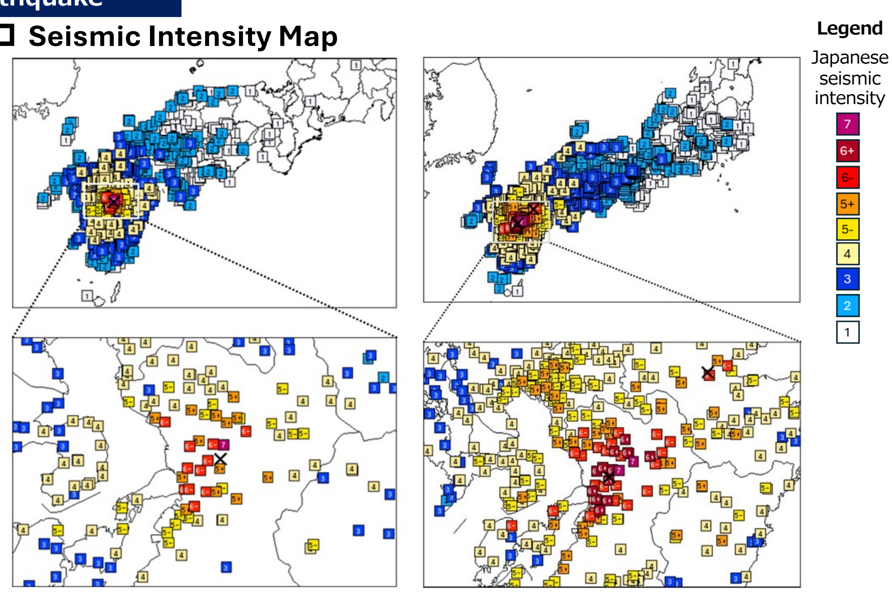
1． Characteristics of the Natural Environment Surrounding Japan's Social Infrastructure and an Overview of Recent Disasters

The 2016 Kumamoto Earthquake

Collapse of Aso Bridge

Large-scale slope slide

□ **Seismic Intensity Map**



April 14, 2016 at 9:26 PM (Heisei | April 16, 2016 at 1:25 AM (Heisei

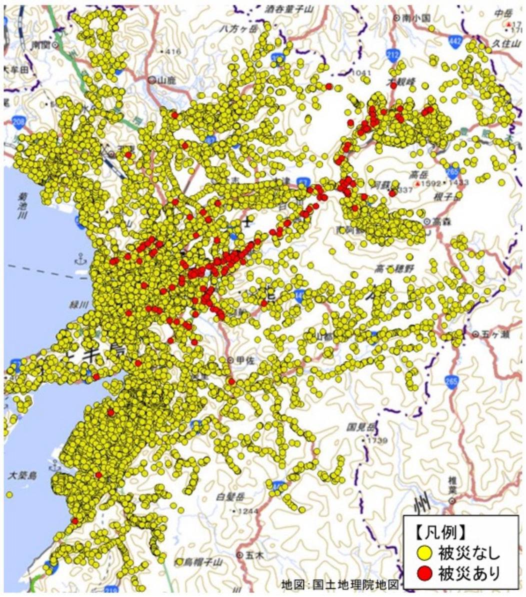
	April 14, 2016	April 16, 2016
Epicenter	The Kumamoto area of Kumamoto Prefecture	The Kumamoto area of Kumamoto Prefecture
Place of Occurrence	Latitude 32°44.5' North, Longitude 130°18.5' East	Latitude 32°45.2' North, Longitude 130°48.7' East
Depth	11km (provisional value)	12km (provisional value)
Magnitude,	6.5	7.3
Japanese seismic intensity	7	7

Source : Japan Meteorological Agency

- The number of bridges in areas within Kumamoto and Oita Prefectures that experienced a seismic intensity 6 or higher is approximately 15,700.
- Among these, there were 182 bridges that have sustained some form of damage.
- there were four bridges that were designed by the seismic code after KOBE Earthquake but did not achieve the targeted seismic performance.

□ Damage Situation of Bridges

Main Areas in Kumamoto with Seismic Intensity 6 or Higher



□ Number of Bridges in Areas with Seismic Intensity 6 or Higher

	Total
Bridges	15,689
Damaged	182

□ Damage Situation of Bridges Designed by the seismic code after KOBE Earthquake(1995)

NO Damage 1,230（98.4%）

Damaged 20 bridges（1.6%）

Target Seismic Performance	Achievement Status
Seismic performance that confines damage to a limited extent and enables prompt recovery of bridge function	4 Bridges
Prevention of Bridge Collapse and Falling	16 Bridges

Source: Road Technology Subcommittee (5th Meeting), Social Infrastructure Development Council, June 24, 2016

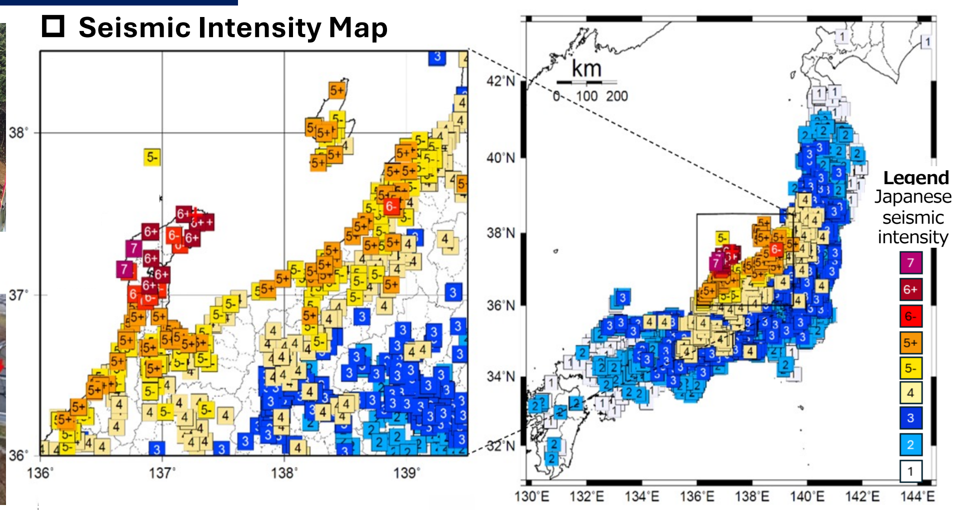
The 2024 Noto Peninsula Earthquake

Large-scale embankment collapses

Failure of reinforced soil wall

Settlement of backfill behind the abutment

□ Seismic Intensity Map



4:10 PM, January 1, 2024 (Reiwa 6)

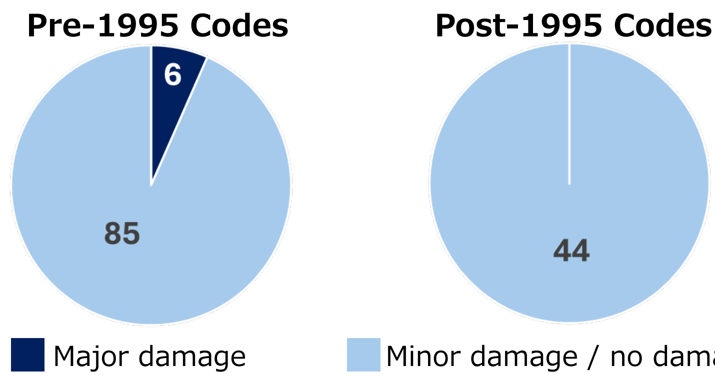
Epicenter	The Noto area of Ishikawa Prefecture
Place of Occurrence	Latitude 37°29.7' North, Longitude 137°16.2' East
Depth	16km (provisional value)
Magnitude,	7.6
Japanese seismic intensity	7

Source : Japan Meteorological Agency

1．Characteristics of the Natural Environment Surrounding Japan’s Social Infrastructure and an Overview of Recent Disasters

The 2024 Noto Peninsula Earthquake

- ■3018 bridges in Ishikawa Prefecture located in areas where the seismic intensity of 6 or higher was observed, no bridges have been reported to have fallen at this time
- ■Bridges designed by the seismic code after KOBE Earthquake(1995),which significantly revised seismic design standards, generally suffered only minor damage.
- ■And more, due to the revision of seismic design standards, no bridge suffered shear failure of piers.
- ■PWRI (Public Works Research Institute) & NILIM (National Institute for Land and Infrastructure Management) jointly investigated damage to 135 road bridges.



※ Excluding damage due to movement of surrounding ground and abutments

➡Revision of seismic code after the 1995 Kobe earthquake seems worked.

Table of Contents

2. Plans and Budget Measures for National Resilience

- Measures to Strengthen National Resilience are being implemented based on the Basic Plan for National Resilience.
- To promote these measures, two budget Measures have been implemented.
- In June this year, the Cabinet approved the First Medium-Term Implementation Plan for National Resilience. Under this plan, Five-year Measures for the next Term(approx. ¥20 trillion) will be intensively implemented

□ History of National Resilience Plans

year	Implementation	Budget Measures
2013年	Enactment of Basic Action for National Resilience	
2014年	Cabinet Decision on the Basic Plan	
2015年		
2016年		
2017年		
2018年	Cabinet Decision on the Revision of Basic Plan	Three-year Emergency Program
2019年		
2020年		
2021年		
2022年		Five-year Acceleration Program
2023年	Cabinet Decision on the Revision of Basic Plan	
2024年		
2025年	Cabinet Decision on the National Resilience Medium-Term Implementation Plan	
2026年		
2027年		
2028年		Five-year Measures For the Next Term
2029年		
2030年		

Source : Source: Road Bureau, MLIT

□ Budget Measures

FY2018-FY2020 Three-year Emergency Program (approx. ¥3.6 trillion)

3-year intensive structural and non-structural measures to be addressed especially urgently.

Measures for road slopes at about 2,000 sites

Bridge retrofittting

Acceleration of utility pole removal for 1,000km

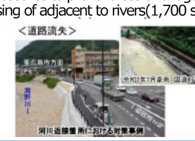
FY2021-FY2025 Five-year Acceleration Program (approx. ¥15 trillion)

- MLIT's long-term goal to improve the road network of essential routes: Back in service 1 day after for emergency vehicles and 1 week after for all vehicles
- 5-year intensive and prioritized measures for further acceleration and deepening

Eliminating about 2,000 missing links

Measures for road slopes and embankments(33,000 sites)

Measures to prevent loss of bridges crossing of adjacent to rivers(1,700 sites)



The next plan will implement over 300 measures, including seismic reinforcement of road bridges and measures for the deterioration of the road structures, with a budget of approximately ¥20 trillion.

Table of Contents

- Initiated in response to a major slope disaster in 1968, the program has conducted ten nationwide inspections at multi-year intervals.
- In response to a series of natural disasters, inspection guidelines were published in fiscal year 1996, and a comprehensive inspection was conducted for all roads.
- Based on the results of this inspection, regular and ongoing inspections have been conducted since fiscal year 1997

□ 1968 Hida River Bus Accident on National Route 41

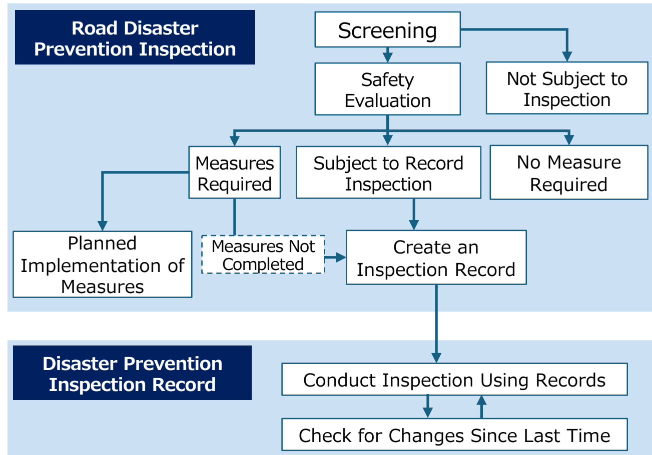
Led to pre-closure rules and disaster prevention inspection systems.

Bus Accident Site※

□ Inspection Targets

Falling Rocks and Landslides	Retaining wall
Rock mass collapse	Scour of Bridge Pier Foundations
Landslide	Ground Blizzard
Avalanche	Others *(Overtopping, Inundation, etc.)*
Embankment	

■ Disaster Prevention Inspection Process



□ Road Disaster Prevention Inspection aims to prevent disasters caused by heavy rain, heavy snow, earthquakes, and other hazards, ensuring safe and secure roads.

- Conduct detailed inspections of road slopes and structures to confirm safety
- Evaluate as **Measures Required**, **Record Inspection** , **No measure Required**
- Detect hazardous locations early and incorporate them into appropriate road disaster prevention measures.

➡ **Utilize collected data for the next inspection and implementation of measures.**

※Source :Japan Federation of Geological Survey and Consulting Associations

□ Development History of the Guidelines

October2021

■MLIT consulted with the Panel regarding ideal disaster prevention and mitigation based on recent disasters.

⇩

March 2022

■MLIT consulted with the Panel regarding draft of ‘Guidelines for Road Risk Assessment Against Natural Disasters’.

⇩

April 2022-

■NILIM is applying the draft to actual road networks

□ Purpose of Road Risk Assessment Guidelines

1. To protect the lives and livelihoods of the public from imminent large-scale earthquakes and increasingly severe and frequent weather-related disasters, it is essential to build a highly reliable road network capable of withstanding relatively frequent natural disasters.This guideline aims to evaluate the current risks to the road network from disasters in order to obtain fundamental data for efficiently and effectively strengthening a disaster-resilient road network.
2. This guideline, in line with the purpose stated in section 1, provides a method to relatively assess the risks of individual roads within the road network. It focuses primarily on disasters of a scale frequently encountered and typically considered in regular road management. This guideline presents a method for comparatively assessing the differences in risks among individual roads by utilizing data used in road management.

■Basic Concept of Road Risk Assessment

〇Basic Concept

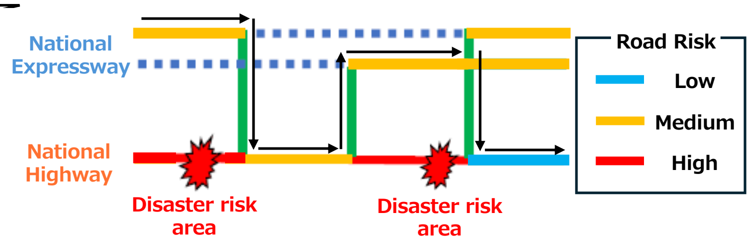
Evaluate the disaster resilience of roads to efficiently and effectively strengthen a disaster-resistant road network.

<Applicable Targets>

Road Development Plan	Consideration of Road Development Priorities	Explanation of Risk Improvement Status

〇Road Risk Assesment (Risk Visualization)

Continuously monitor and update the performance and risks of roads.



⇒ Evaluating disaster resilience across different structures and routes using a consistent method

⇒ Evaluate by correlating road disaster resilience with performance based on design standards

⇒ Shift from focusing on individual road structures to focusing on the entire road network

＋

・Actively utilize specification and inspection data, updating the data regularly.

・Enhance evaluations continuously by improving design standards.

Source: Road Technology Subcommittee (16th Meeting), Social Infrastructure Development Council, March 22, 2022

■Based on the assumed damage to road structures caused by anticipated hazards, road risks are evaluated by considering the degree of traffic function degradation (vulnerabilities), the possibility of road closures or traffic restrictions, and the ease of functional recovery.

■Process of Road Risk Assessment

■ Input hazards

-Torrential rains for a reference period of 100 years

-Rare-scale earthquakes and frequently generated earthquakes

-Hazard induced by geological conditions and others outside the road

⇩

■ Anticipate deformations (vulnerabilities) of road structures

⇩

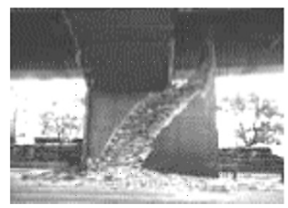
■ Anticipate the degree of functional degradation (extent of disruption) of traffic

⇩

■ Evaluating road risk based on potential closures/restrictions and ease of functional recovery

3．Disaster Mitigation Measures and Risk Management Road Risk Assessment

- In the guidelines, Road risk is defined as the possibility of restrictions (such as speed limits, lane closures, or weight limits) arising from a specific hazard.
- The evaluation of road risk is conducted by relatively assessing the scale of possibilities.

	Speed limitations	Lane closure or reductions	Weight limitation
High likelihood of no traffic restrictions			
Possible temporary closure, but likely accessible with limited restrictions			
High likelihood of road closure			

Source: Road Technology Subcommittee (16th Meeting), Social Infrastructure Development Council, March 22, 2022

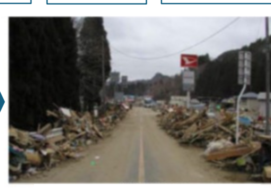
3．Disaster Mitigation Measures and Risk Management Formulation of Road Clearing Plan

- After the earthquake, roads are quickly cleared to allow emergency vehicles to pass by removing debris and making simple repairs.
- To enhance initial disaster response following the Noto Peninsula Earthquake, making the formulation and specification of road clearing plans became a legal requirement in 2025.
- The plan is scheduled to be formulated and published by the end of next fiscal year.

Road Clearing Process

Disaster Occurrence → **Road Clearing** → Emergency Restoration → Permanent Restoration → Reconstruction

Damage Situation



After Road Clearing

Source : MLIT Website

Basic Framework of Road Clearing Plan

1 Targeted Disasters

2 Road Clearing Goal | 3 Priority Routes and Sections

4 Implementation Method

5 Stockpiling and Procurement of Equipment and Materials

6 Information Gathering and Communication

7 Trainig | 8 Others

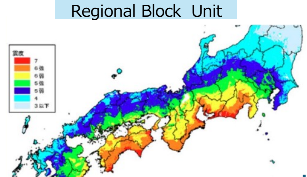
Targeted Natural Disaster
- Earthquakes Tsunami
- Volcanic Disaster
- Snow Damage
- Storm and Flood Damage

Planning Unit
- Regional Block Unit
- Prefectural Unit

1．Targeted Disasters（Example : Earthquake）

< Regional >

Regional Block Unit

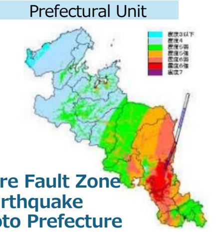


Nankai Trough Earthquake

Source : Central Disaster Prevention Council

< Local >

Prefectural Unit

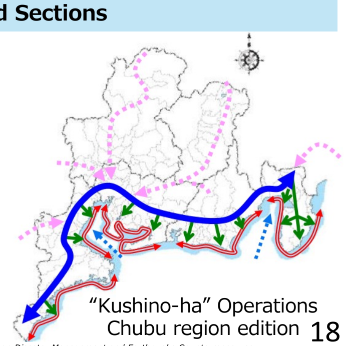


Hanaore Fault Zone Earthquake in Kyoto Prefecture

Source : Nara Prefecture, "Hanaore Fault Zone Earthquake Damage Assessment"

2．Road Clearing Goal
3．Priority Routes and Sections

- Within approximately 1 day — STEP 1: Regional Support Network/Route
- Within 1–2 days — STEP 2: Route for Accessing the Disaster Area
- Within 3 days — STEP 3: Route within the Disaster Area



"Kushino-ha" Operations Chubu region edition

Source : Chubu Regional Trunk Road Council, Subcommittee on Disaster Management and Earthquake Countermeasures

3．Disaster Mitigation Measures and Risk Management Emergency Inspections and Actions

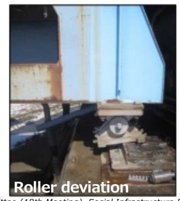
- ■ From a risk management perspective, emergency inspections are conducted after a major earthquake, and necessary measures are implemented accordingly.
- ■ We learn new lessons from the damage, assess the impact on existing road structures, and implement repair and reinforcement measures accordingly.

Seismic Reinforcement of Rocking Piers <2016 Kumamoto Earthquake>

Source: Road Technology Subcommittee (5th Meeting),Social Infrastructure Development Council, June 24, 2016

- ☐ Four bridges overpassing expressways in Kumamoto Pref were damaged, including one bridge with rocking piers that collapsed
- ☐ Seismic reinforcement of approximately 450 bridges with rocking piers on expressways, national highways, and those overpassing these road was completed by FY2021.

Step Prevention Device <2022 Fukushima Earthquake>



Source: Road Technology Subcommittee (18th Meeting), Social Infrastructure Development Council, March 13, 2023

- ☐ The bearings of steel truss bridges specified as pin bearings and pin-roller bearings were damaged.
- ☐ MLIT notified road administrators that it is desirable to give priority to considering seismic retrofitting measures—such as step prevention devices—for truss and arch bridges.

Embankment Slope <2024 Noto Peninsula Earthquake>

☐ Inspection Status (As of the end of March, 2025)

Type of Road	Inspection Sites	Sites Requiring Measures	States of Progress
National Expressway	Approx. 900 sites	74 sites	Inspection is complete
National Highway	Approx. 1,500 sites	271 sites	Inspection is complete Measures are underway at 26 sites
Prefectural Road Municipal Road	Approx. 5,700 sites	Under Inspection	Inspection completed at about 800 sites

Source: Road Technology Subcommittee (25th Meeting), Social Infrastructure Development Council, March 21, 2025

- ☐ Large-scale embankment collapses occurred in the embankment sections of the Noetsu Expressway.
- ☐ In response, emergency inspections of high embankments have been conducted along emergency transport routes nationwide.
- ☐ In order to support local government, a subsidy program for measures of road embankment was established in FY2025.

APPENDIX D TOPIC 2 PRESENTATION SLIDES

U.S. Department of Transportation
Federal Highway Administration

Day 2 Topic
Seismic Retrofit for Bridges and Structures

U.S. Department of Transportation
Federal Highway Administration

Subtopics

A. Retrofitting Methods and Programming
B. Target seismic performance and field observations
C. Durability and consideration of other design/maintenance factors
D. Post-event management
E. New technology, knowledge update
F. Research needs/Roadmap

U.S. Group Members

Ian G. BUCKLE, University of Nevada, Reno

Andrew FISKE, Washington DOT

Amy LELAND, Washington DOT

Lee MARSH, WSP

Khalid MOHAMED, FHWA

Tom MURPHY, Modjeski & Masters

Nick MURRAY, Alaska DOT&PF

Albert NAKO*, Oregon DOT

Jerry SHEN, FHWA

Chris TRAINA, Caltrans

David YANG, Portland State University

Tony YOON, Caltrans

(Alphabetic)

*Will not participate in-person

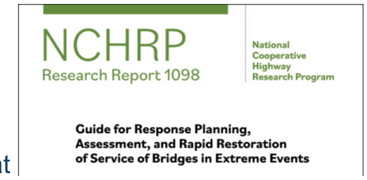
FHWA Seismic Design/Retrofit Milestones

- FHWA funded the Applied Technology Council (ATC) to prepare a synthesis report on seismic bridge design (ATC-6, 1981), adopted in 1983 as a guide specifications.
- ATC 6-2 project produced a retrofitting manual in 1983, updated in 1995, 2006.
- *Seismic Design of Highway Bridge Foundations* was completed in 1986.
- NCEER 1992: Seismic Vulnerability of Existing Highway Construction, Seismic vulnerability of new highway construction
- MCEER 1998:Seismic Vulnerability of the Highway System
- NCHRP 12-49, 20-7 Task 193
- 2007 ABC Innovative Technologies and Their Applications to Enhance the Seismic Performance of Highway Bridges
- 2012 Transportation Pooled Fund solicitation: Validation of Tsunami Design Guidelines for Coastal Bridges

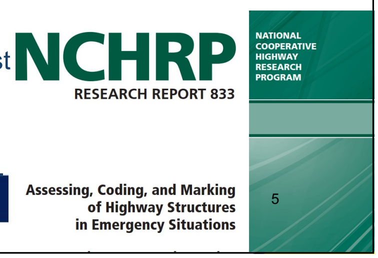
Post-event Damage Inspection (PDI)

- PDI **assessing the performance of transportation systems following extreme events** is key to ensure rapid and functional recovery.
- PDI is typically the **first step towards evaluating the performance of the assets and making decisions for immediate measures** that aim at minimizing interruption of services while ensuring public safety.
- PDI typically occurs **within 24-hours** from an extreme event and is typically referred as ‘Evaluation Procedure,’ ‘Safety Evaluation,’ ‘First Responder Assessment,’ etc.
- Available PDI protocols and procedures vary from one agency to another, and in some cases, are state-, hazard- or structure-specific.

NCHRP 14-45 Rapid Bridge Service Restoration



NCHRP 14-29 explored elements of PDI



Post-event Engineering Investigation (PEI)

- PEI refers to **field investigations conducted mainly by teams of engineers and natural disaster scientists** where asset performance data are collected and presented
- PEI aims at documenting **(1) the performance of infrastructure**, **(2) lessons learned from a natural disaster**, and **(3) needs for existing design and construction methodologies to be modified or enhanced.**
- PEI may occur **within hours or weeks** from an extreme event following a PDI and is typically referred to as **‘Reconnaissance Mission’**
- PEI protocols and procedures vary from one agency to another, and in some cases, are state-, hazard- or structure- specific.

Extreme Events in Asset Management Planning

- Framework that builds into existing bridge management systems

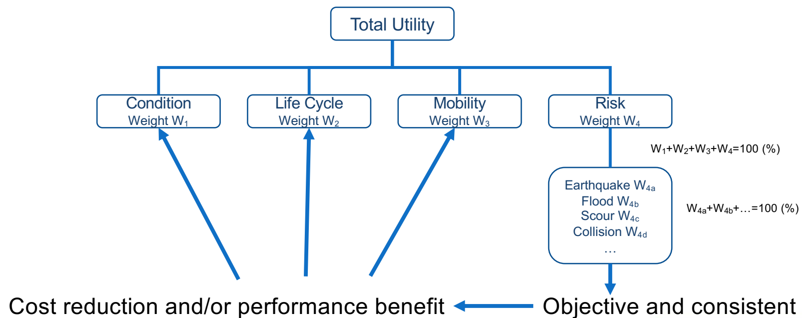


Image: FHWA

Bridge life cycle considerations

- Condition rating, condition state
- Actions: preservation (maintenance, repair, rehabilitation, replacement), safety enhancement, protection, functional improvement, detailed action (bridge level)
- Agency cost, user cost
- Benefits (effects from actions)
- Action policy (rehabilitation, repair, replacement, …)

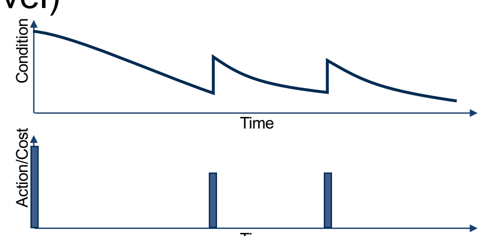


Image: FHWA

Life-cycle cost analysis

- Annual cost calculation

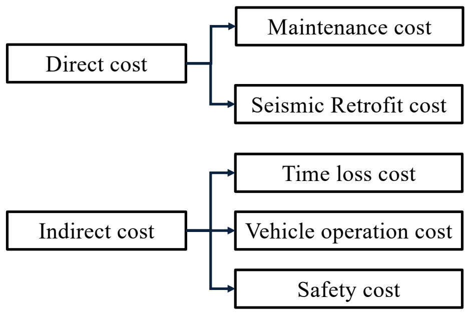


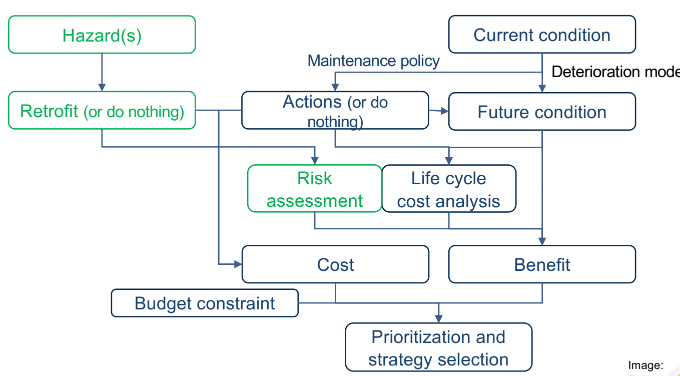
Image: FHWA

- Life-cycle cost aggregation

$$C_{Lifecycle} = \sum_{t=1}^{T} \gamma^{t} C(t)$$

Bridge Management Decision-Making

- Maximizing benefit – objective(s)
  - Ex. Performance index, condition ratings, safety, risk, mobility
- Minimal cost
- Budget/resource constraint



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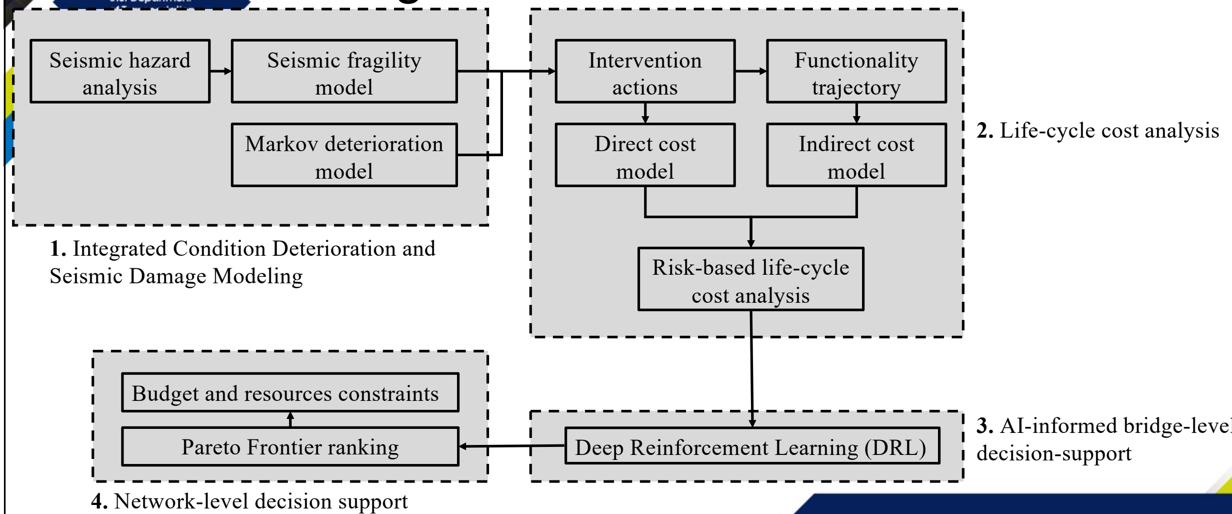
AI-Informed Risk-Based Bridge Asset Management Framework



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AI-informed bridge-level decision-support

Reinforcement Learning for Sequential Decision Making:

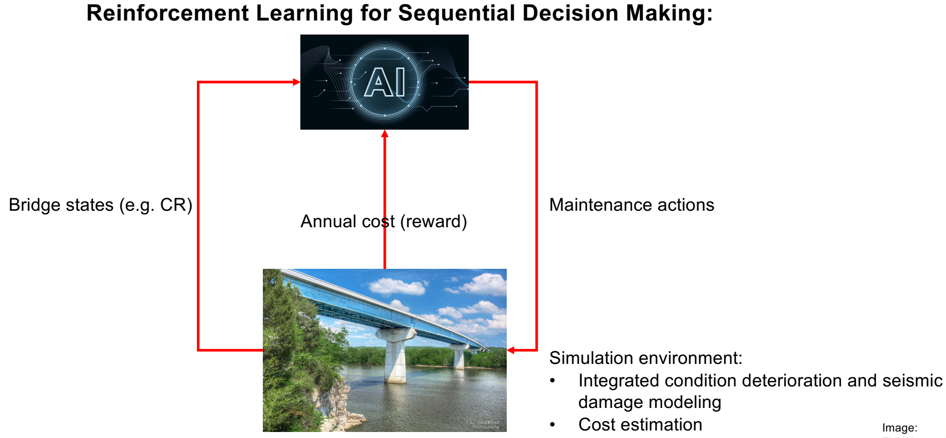
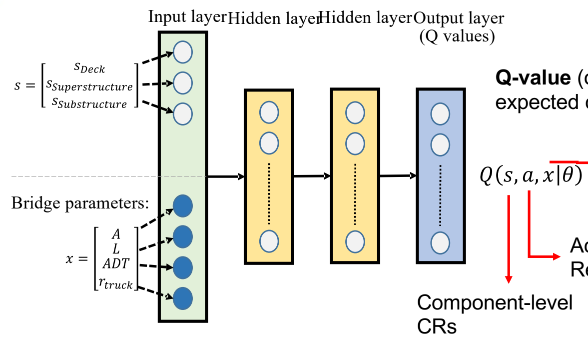


Image: FHWA

AI-informed bridge-level decision-support

Parameterized Deep Q Network



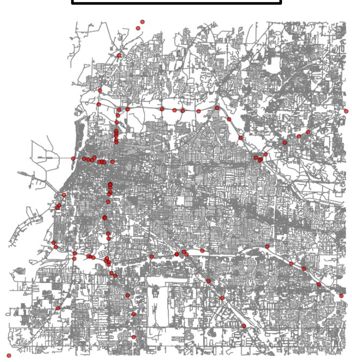
Q-value (or action-state value) is a measure of the expected cumulative long-term (life-cycle) reward

The trained AI policy can then be applied to any individual bridge

Image: FHWA

Network-level decision support

Bridge network



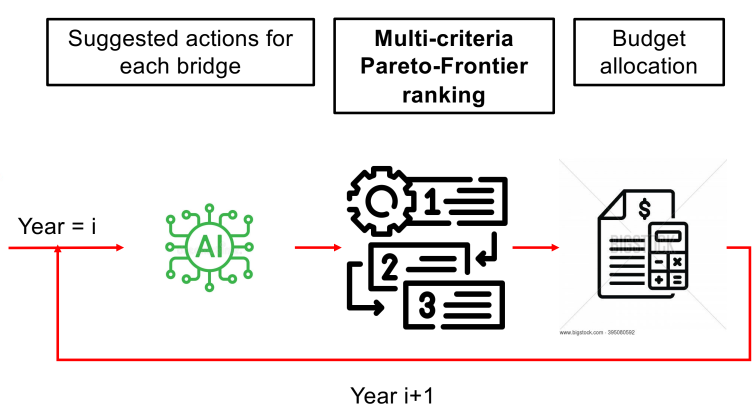
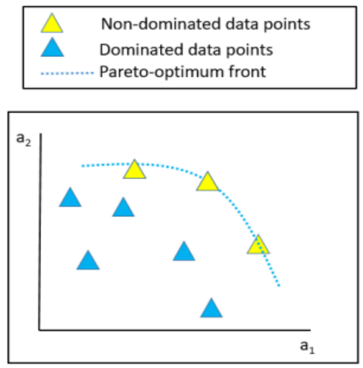


Image: FHWA

Network-level decision support

Multi-Criteria Pareto Frontier ranking

- Multi-attribute ranking using non-dominated sorting algorithms (NSGA).
- Can effectively and efficiently rank bridge projects based on multiple project-related attributes (e.g., CR, ADT, deck area, Q values).



(b) Pareto-optimum front maximizing parameter set (a_1 , a_2)

Image: FHWA

Potential future retrofit approach: Residual displacement control

- Post-event functionality and long-term serviceability
- Impact on user perception of damage
- Self-centering technology
- Proper shaping and scaling of hysteresis behavior
- Examples: Shape memory alloy, post-tensioned column

Potential future retrofit approach: Approach embankment performance and slope management

- Updating guidance and reducing uncertainties for liquefaction hazards
- Foundation retrofits
- Monitoring of slopes and retaining structures
- Drainage system for embankments and slopes
- Managing abutment movement on steep slopes
- Geotechnical asset management approaches

Potential future retrofit approach: Multi-hazard and robust detailing

- Economical enhancement of structural robustness
- Details working for multiple extreme event loads
  - Tsunami, landslide, collision

U.S. Department of Transportation
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Topic 2-F
Research Needs and Roadmap

Seismic Retrofit of Bridges and Structures

U.S. Department of Transportation
Federal Highway Administration

Day 2 Topic
Seismic Retrofit for Bridges and Structures

U.S. Department of Transportation
Federal Highway Administration

Subtopics

A. Retrofitting Methods and Programming
B. Target seismic performance and field observations
C. Durability and consideration of other design/maintenance factors
D. Post-event management
E. New technology, knowledge update
F. Research needs/Roadmap

U.S. Group Members

Ian G. BUCKLE, University of Nevada, Reno

Andrew FISKE, Washington DOT

Amy LELAND, Washington DOT

Lee MARSH, WSP

Khalid MOHAMED, FHWA

Tom MURPHY, Modjeski & Masters

Nick MURRAY, Alaska DOT&PF

Albert NAKO*, Oregon DOT

Jerry SHEN, FHWA

Chris TRAINA, Caltrans

David YANG, Portland State University

Tony YOON, Caltrans

(Alphabetic)

*Will not participate in-person

Topic 2-A Retrofitting methods and programming

Seismic Retrofit of Bridges and Structures

Retrofitting methods and programming Brief Presentations

- FHWA Seismic Retrofit Manual (Ian G. BUCKLE)
- California Seismic Retrofit for State and Local Bridges (Chris TRAINA)
- Brief history, current program, and guidance in Japan (Akiko HIROE)

Retrofitting methods and programming Discussion

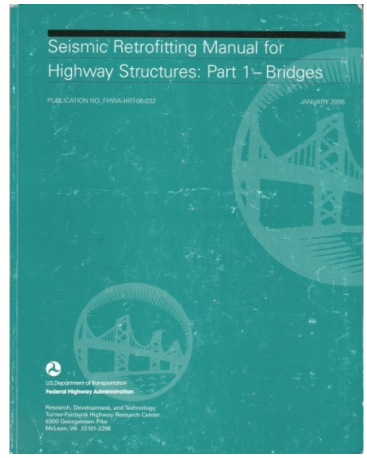
1. Programmatic principles and procedures for bridge seismic retrofit in Japan.
2. Methods for planning bridge maintenance actions corresponding to retrofit actions
   a. Phased approach,
      Multi-purpose projects addressing multiple structural deficiencies, and special considerations in tsunami inundation areas
   b. Network performance, life-cycle analysis, life-cycle cost, and remaining service life considerations in prioritizing retrofit projects

FHWA Retrofitting Manual for Highway Structures

Material presented is based on the FHWA Retrofit Manual:

Seismic Retrofitting Manual for Highway Structures: Part 1- Bridges (2006) FHWA Report HRT-06-032

Manual is advisory in nature and not a formal specification. Owners and engineers are free to modify the recommendations and procedures contained therein according to local conditions and practices.

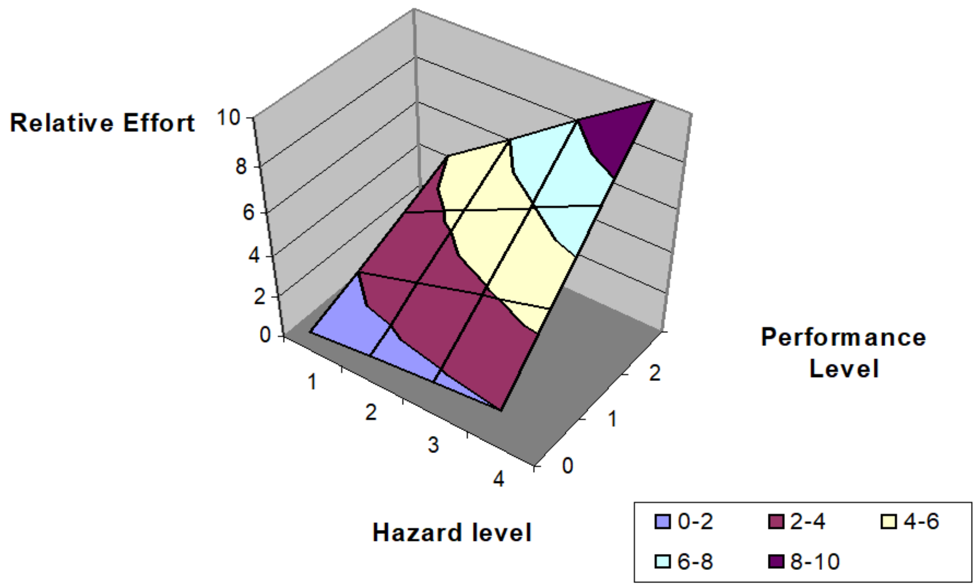


Performance-Based Retrofitting

Explicit attempt to satisfy public expectations of bridge performance for earthquakes ranging from small to large… for example:

Performance	Earthquake Size		
	Small	**Intermediate**	**Large**
No interruption	✓	✓	
Limited access		✓	✓
Closed for repairs			✓

Effort vs. Hazard and Performance Level



Application of Performance-Based Design to Retrofitting

02 **Earthquake levels**
- Lower
- Upper

03 **Service life categories**
- ASL1
- ASL2
- ASL3

02 **Bridge types**
- Standard
- Essential

03 **Performance levels**
- Life safety
- Operational
- Fully operational

Performance Levels: 1, 2, and 3

01

Life Safety

- No collapse
- Life-safety preserved
- Damage will be severe particularly after Upper Level (UL) event
- Service significantly disrupted
- Bridge may need replacement after UL event

02

Operational

- No collapse
- Life-safety preserved
- Damage is minor
- Almost immediate access for emergency vehicles
- Repairs feasible but with restrictions on traffic flow

03

Fully Operational

- No collapse
- No damage
- No interruption to traffic flow
- No repair required

Performance Levels: Lower-Level Event

Earthquake	Bridge Importance and Service Life					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Lower Level (100-yr Event)	Exempt	Fully Operational		Exempt	Fully Operational	

Performance Levels: Upper-Level Event

Earthquake	Bridge Importance and Service Life					
	Standard			**Essential**		
	ASL1	ASL2	ASL3	ASL1	ASL2	ASL3
Upper Level (RTGM)	Exempt	Life Safety		Exempt	Life Safety	Opera-tional

Seismic Retrofit Process

01 Screening and prioritization

02 Detailed evaluation of both capacity and demand

03 Selection and design of retrofit strategy

Retrofit Process for Two Earthquake Levels

01

Screen, evaluate, retrofit for performance required during **Lower-Level** earthquake (100-yr)

Performance required:
Fully operational

02

Screen, evaluate, retrofit for performance required during **Upper-Level** earthquake (RTGM)

Performance required:
Life-safety and operational

Screening and Prioritization

Screen / Prioritize → Evaluate → Retrofit

Screening	Prioritization
Purpose: Screen an existing inventory of bridges for seismic deficiencies	**Purpose**: Prioritize the inventory for seismic retrofitting based on vulnerability, hazard, and non-structural factors
Methods are expected to be quick and conservative Bridges that 'fail' are passed to a second level of screening (i.e. 'detailed evaluation')	Places bridges in need of detailed evaluation, and perhaps retrofitting, in order of attention

Methods to Calculate Rank and Prioritize Need for Retrofit

01 Indices

R = Vulnerability index
x Hazard index
$\leq$ 100
P = f(R, other)

02 Expected Damage

Uses bridge fragility functions to estimate damage. Rank and prioritization based on direct losses due to damage.

03 Bridge Management

Uses principles of Bridge Management Systems (BMS) to estimate condition and prioritize repair across all hazards, in addition to maintenance actions.

04 Network Assessment

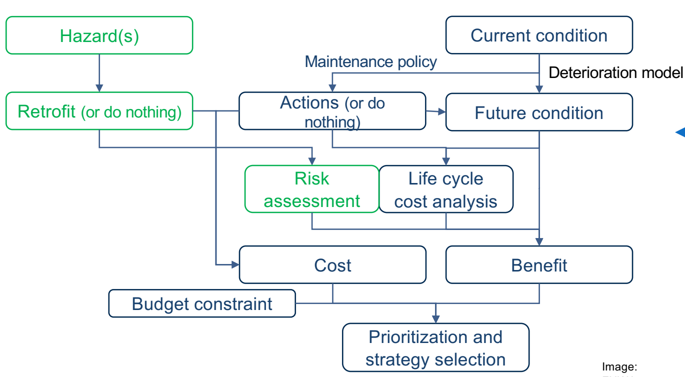
Uses network models, fragility functions, and seismic demand.

Rank is based on direct and indirect losses. Uses REDARS-Lite software or ShakeCast or similar

FHWA Retrofitting Process for Highway Bridges

U.S. Department of Transportation
Federal Highway Administration

Asset management provides decision support not only for retrofitting but also competing maintenance needs.



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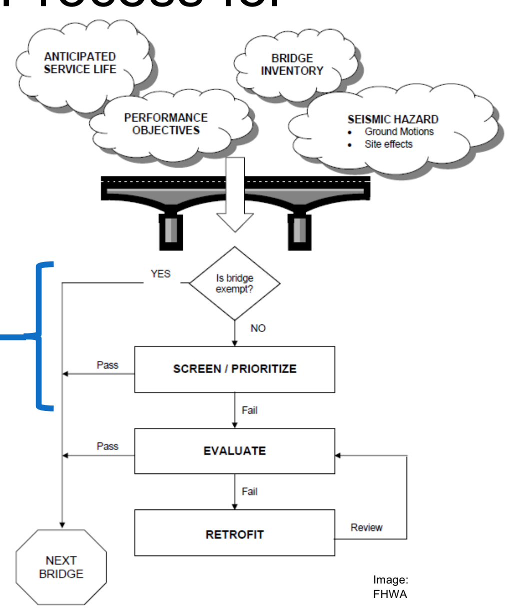


Image: FHWA

Methods of Evaluation

Screen / Prioritize → **Evaluate** → Retrofit

In general, all evaluation methods involve:

- Demand analysis
- Capacity assessment
- Calculation of a capacity / demand ratio either for
  - Each critical component in a bridge
  - Bridge as a complete system

Retrofit Design Steps

Screen / Prioritize → Evaluate → **Retrofit**

01 Decide strategy

02 Select approach

03 Design measures

Retrofit Strategies, Approaches, Measures

Strategies

1. One or more approaches used together
2. Replacement
3. Do-nothing

Approaches

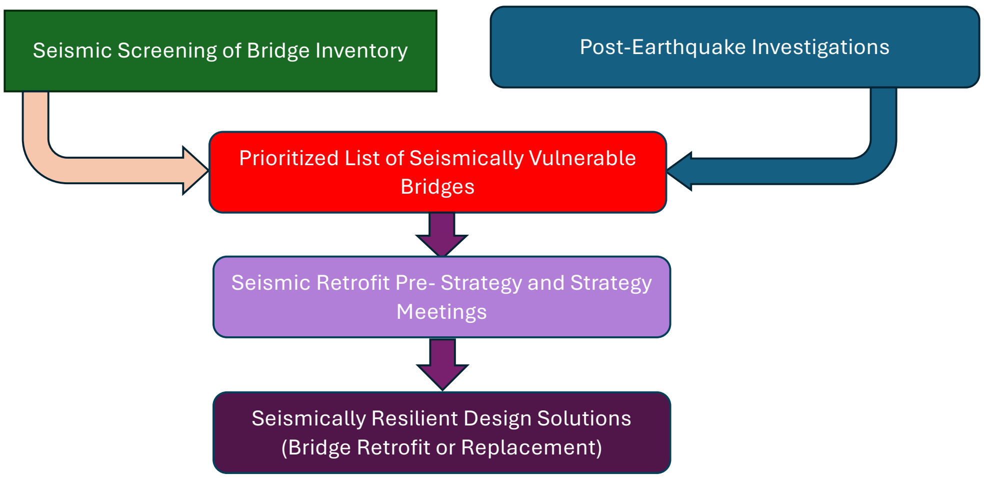
1. Strengthening
2. Displacement capacity enhancement
3. Force limitation
4. Response modification
5. Site remediation
6. Partial replacement
7. Damage acceptance

Measures

1. Restrainers
2. Seat width extenders
3. Seismic isolators
4. Column jackets
5. Infill walls
6. Footing overlays
7. Supplementary piles
8. Stone columns

Thank You!

California Bridge Retrofit Process



Caltrans Past Seismic Screening Activities

- <u>1971 San Fernando (Mw 6.6)</u>
  - First implementation of PEQIT
    - Caltrans screened state-owned bridges for short seats and vulnerable columns
    - Cable restrainer retrofit of 1,400 state-owned bridges.
    - Column confinement was key finding.

- <u>1989 Whittier Narrows (Mw 5.9)</u>
  - Column retrofit program initiated

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Caltrans Past Seismic Screening Activities

- -1989 Loma Prieta (Mw 6.9)
  - Caltrans screened all state (12,500) and locally (over 12,000) owned bridges
  - Improved connection details
- -1994 Northridge (Mw 6.7)
  - Caltrans rescreened state bridges with a focus on lessons learned.
  - Column stiffness balancing within frames
  - Increasing seat widths at supports

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Caltrans Past Seismic Screening Activities

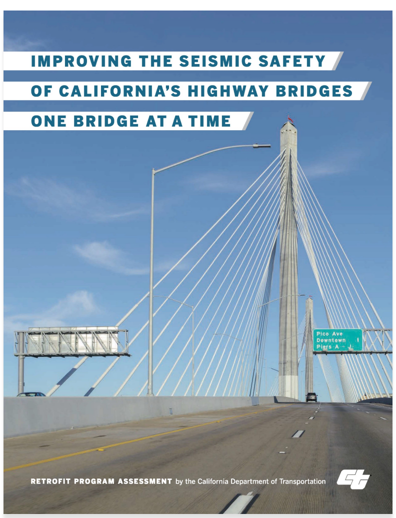
- 2003 State Bridge Screening
  - All state bridges screened for shear critical columns and grouted restrainers.
- 2015 State Bridge Screening
  - Increased ground shaking.
  - Fault offset hazards.
  - Liquefaction and lateral spreading.
- 2019 State Bridge Screening
  - Increased ground shaking.
  - Vulnerable lap splices between columns and foundations.

Current Seismic Screening Activities

- <u>2024 Local Agency Bridge Screening</u>
  - Increased ground shaking.
  - Fault offset hazards.
  - Liquefaction and lateral spreading.

  - Increased ground shaking.
  - Vulnerable lap splices between columns and foundations.

Caltrans Retrofit Program Assessment



CALIFORNIA'S TRANSPORTATION NETWORK HAS OVER 26,500 BRIDGES that carry roads over natural and manmade obstacles. Every hour these elevated structures facilitate the movement of people and goods, and any hour a destructive earthquake can strike. When a bridge is out of service, the network is severed, which disrupts traffic, prevents access to communities, and impacts post-earthquake emergency response. Extensive bridge damage or collapse can threaten life safety and adversely affect Californians and the economy.

After the 1989 Loma Prieta earthquake, it was recognized that improving the seismic resistance of California's bridges would require sustained investment in research and new State-funded programs to seismically improve or replace State Highway System (SHS) bridges, toll bridges, and local bridges.

As part of the 1990 seismic retrofit program, Caltrans screened all SHS bridges for seismic vulnerabilities that could lead to collapse during a large earthquake. Most bridges were deemed adequate to survive without retrofitting. Over 25% of the SHS bridges in service at the time were retrofitted or replaced to lower the probability of collapse during a large earthquake.

13,246	State-owned highway bridges
$160 BILLION	Estimated value of State bridge inventory
8,500	SHS bridges built between 1945–75, before California had developed advanced seismic design standards for bridges
$12.2 BILLION	Cost to retrofit or replace 3,613 State bridges as of 2017
13,343	Bridges owned by local agencies
$1.4 BILLION	Cost to retrofit or replace 1,175 locally owned bridges as of 2017
$9 BILLION	Cost to retrofit or replace the State's 9 toll bridges
650	State bridges that are vulnerable to seismic activity and need to be retrofitted or replaced

Improvements in seismic design for new and retrofitted bridges have drastically reduced the probability of a collapse due to an earthquake. California's bridges constructed after 1990 are expected to have a low probability of collapse and be able to return to service soon after a major earthquake.

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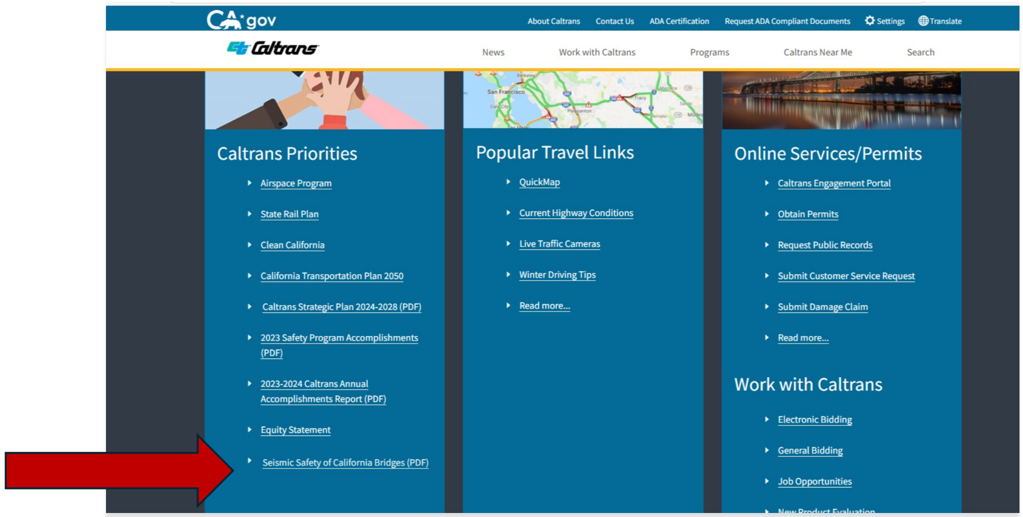
Caltrans Retrofit Program Assessment



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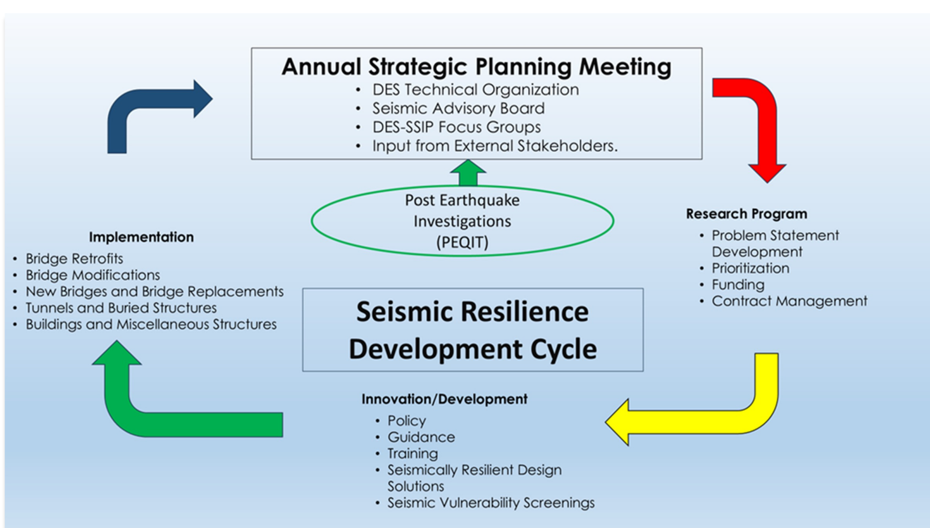
Caltrans Seismic Strategies and Implementation Plan (DES-SSIP)



Caltrans Seismic Strategies and Implementation Plan (DES-SSIP)

Seismic Resilience of Existing Structures Focus Area Primary Strategies:

- Perform research on the response of existing bridges subject to seismic hazards related to liquefaction, fault offsets, lateral spreading, and/or slope stability to develop policy and design guidance for the seismic retrofit of bridges
- Increase funding in the SHSMP to complete the retrofit of vulnerable state bridges from a prioritized list of projects
- Conduct advanced screening and prioritization for the retrofit of bridges with liquefaction and potential lateral spreading hazards
- Update Caltrans standards for the retrofit of bridges with different seismic hazards
- Set policy and funding for Caltrans to screen (and possibly retrofit) local agency bridges

Seismic Resilience of Existing Structures Focus Area Intended Outcomes:

- Development of design guidance and policy for the seismic retrofit of bridges. This includes the development of STP 16.7 Seismic Retrofit Policy for Bridges in California and BDM 16.7 Seismic Retrofit Guidance for Bridges in California
- Training through annual workshops for the Bridge Designers on seismic retrofit of existing structures
- Improve the seismic resilience of bridges on the State and Local Highway networks

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Update to Seismic Retrofit Policy and Guidance

LRFD

MEMO TO DESIGNERS 20-4 • JUNE 2016

20-4 SEISMIC RETROFIT GUIDELINES FOR BRIDGES IN CALIFORNIA

Introduction

Caltrans *Memo to Designers* (MTD) 20-4 describes policies and procedures for the seismic retrofit of California's bridges.[1] Caltrans, *Bridge Design Aids* (BDA) 14-5 and *Bridge Standard XS Detail Sheets* Section 7 include common retrofits that can be used by designers. The Federal Highway Administration has published a bridge retrofitting manual (Buckle, 2006), with examples of common retrofits. This manual is a useful reference, however the specifications and details are not approved by Caltrans.

While MTD 20-4 is intended to provide guidelines for retrofitting existing structures, it is not possible to anticipate every situation that may be encountered. It is the designer's responsibility to accurately assess the performance of the existing structure, to show a collapse mechanism if it exists, and to develop retrofit strategies that ensure the structure meets the no collapse performance standard.

Expected Performance

The primary performance standard for retrofitting bridges is to prevent the structure from reaching the collapse limit state[2] for the Design Earthquake[3]. The goal of this "No Collapse" performance standard is to protect human life and there are no serviceability expectations for retrofitted bridges.

An acceptable determination of collapse is captured through an analysis of the bridge model subject to the Design Earthquake. However, determining collapse is different than simply determining that demand exceeds capacity. First of all, capacity is more conservatively

Bridge Design Memo 16.7 • July 2025

16.7 SEISMIC RETROFIT GUIDANCE FOR EXISTING BRIDGES IN CALIFORNIA

16.7.1 GENERAL

Designers may be assigned an existing bridge to analyze for a possible retrofit from:

- Bridges in the State Highway Operation and Protection Program (SHOPP); ranked by seismic risk through seismic screening and pre-strategy meetings.
- Bridges that require major modifications, putting them at higher seismic risk, may require retrofit as described in Structure Technical Policies (STP 16.2) Modifications to Existing Structures that Increase Dead Load.

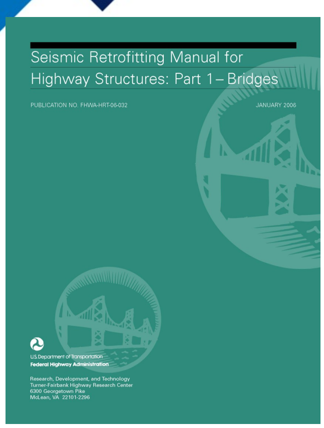
This memo provides seismic retrofit guidance to minimize the probability of collapse for existing bridges subject to the Design Earthquake and associated hazards. This memo includes guidance to determine the need for a seismic retrofit and the process to formulate a minimum retrofit strategy to achieve the expected seismic performance for existing bridges.

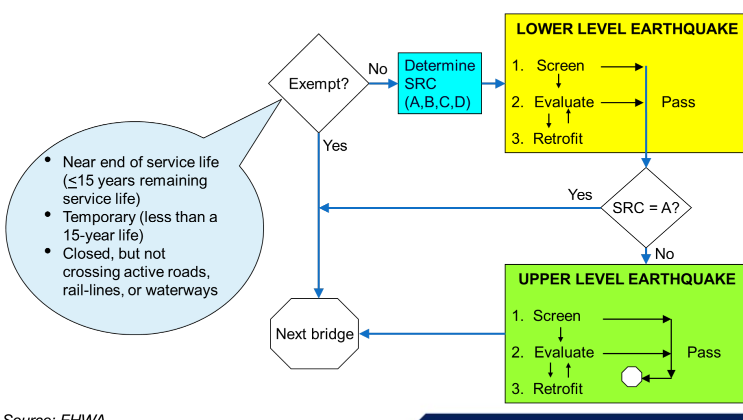
16.7.4 EXPECTED PERFORMANCE

The primary performance standard for retrofitting existing bridges is to minimize the probability of collapse for the Design Earthquake. The goal of this "Expected Performance" is to protect human life, with no consideration of serviceability requirements.

Thank You!

Seismic Evaluation Process





Source: FHWA

Performance-Based Retrofitting

EARTHQUAKE GROUND MOTION	BRIDGE IMPORTANCE and SERVICE LIFE CATEGORY					
	Standard			Essential		
	ASL 1	ASL 2	ASL 3	ASL 1	ASL 2	ASL 3
Lower Level Ground Motion 50 percent probability of exceedance in 75 years; return period is about 100 years.	PL0[4]	PL3	PL3	PL0[4]	PL3	PL3
Upper Level Ground Motion 7 percent probability of exceedance in 75 years; return period is about 1,000 years.	PL0[4]	PL1	PL1	PL0[4]	PL1	PL2

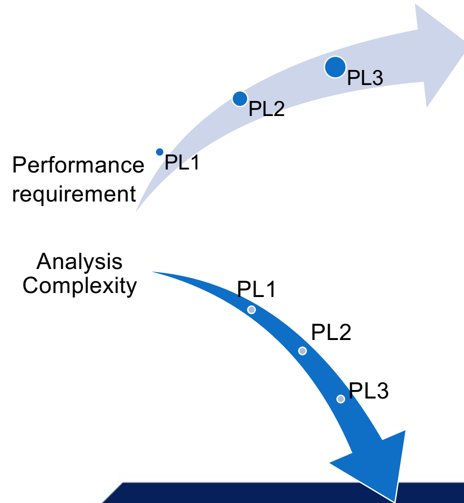
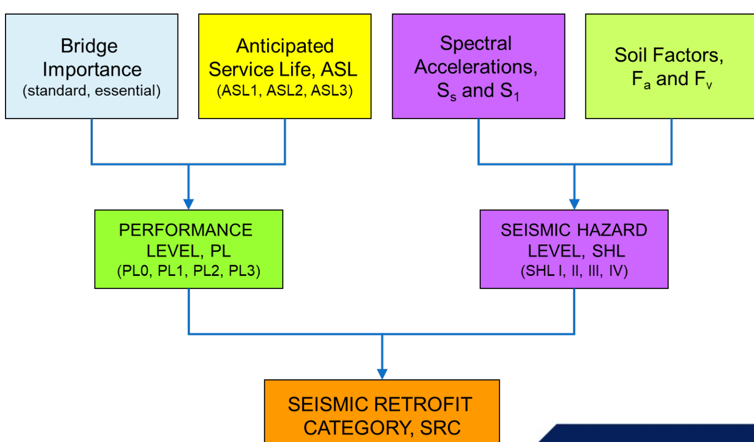


Image: FHWA

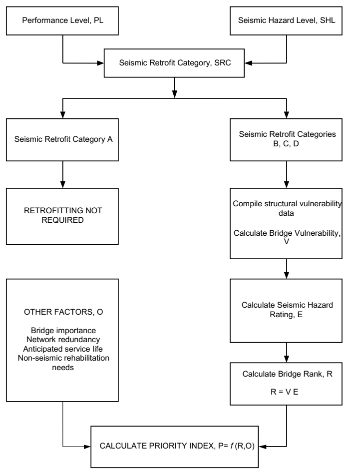
Seismic Screening – Retrofit Category



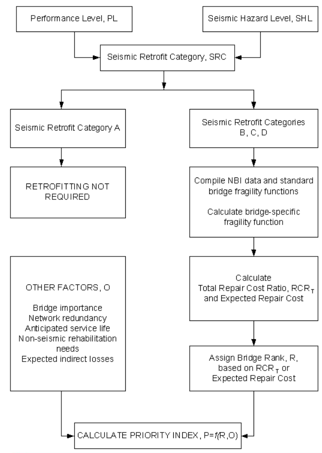
Source: FHWA

Screening Methods

Indices Method



Expected Damage Method



Source: FHWA

FHWA Retrofit Strategies, Approaches, and Measures

- Strategies
  - Do nothing
  - Partial Retrofit
  - Full Retrofit
  - Partial replacement
  - Full replacement
- Approaches
  - I. Strengthening.
  - II. Improvement of Displacement Capacity.
  - III. Force Limitation.
  - IV. Response Modification.
  - V. Site Remediation by Ground Improvement.
  - VI. Acceptance or Control of Damage to Specific Components.
  - VII. Partial Replacement.
- Measures
  1. Diaphragm strengthening.
  2. Energy dissipating ductile diaphragms.
  3. Provision of longitudinal continuity in simply supported spans.
  4. Replacement of bearings.
  5. Seismic isolation bearings.
  6. Energy dissipators.
  7. Seat width extensions and catcher blocks at girder supports and intermediate hinges.
  8. Restrainers at girder supports and intermediate hinges.
  9. Column replacement.
  10. Concrete shells, steel and fiber-composite jackets for columns.
  11. Infill shear walls in bents.
  12. Cap beam strengthening using prestressing.
  13. Supergirders.
  14. Anchor slabs behind abutments.
  15. Soil and gravity anchors.
  16. Abutment shear keys.
  17. Footing replacement.
  18. Footing overlays.
  19. Pile tie-down enhancement.
  20. Supplemental piles.
  21. Articulation for fault crossings.
  22. Site remediation for unstable slopes and liquefaction.
  23. Vibro-replacement of soils and stone columns.

Alaska Bridge Retrofit Screening Process

- Significant effort went into developing an Importance factor that reasonably reflected state priorities and unique qualities of state in the 1990's

$$I = 1 * RT_{carry} * DL_{carry} * N_{carry} + \frac{1}{4}\left(\frac{ADT_{carry}}{6000L}\right)^{0.25} + \frac{2}{3}\left(RT_{cross} * DL_{cross} * N_{cross}\right) + RV_{cross}$$

- RT_{carry}: Type of route (highway, local road, etc)
- DL_{carry}: Detour length
- N_{carry}: Function of traffic volume
- $\frac{1}{4}\left(\frac{ADT_{carry}}{6000L}\right)^{0.25}$: Function of traffic volume & bridge length (longer bridge would take longer to repair/rebuild)
- $\frac{2}{3}\left(RT_{cross} * DL_{cross} * N_{cross}\right)$: For overpasses, how important is the route below?
- RV_{cross}: River crossing factor (harder to make repairs, shoring or temporary bridges over rivers)

- There are very few detour routes in Alaska so all bridges first appeared very high in rankings because of single variable driving entire decision-making process
- This importance factor is multiplied by the vulnerability and the seismic hazard to arrive at a final ranking

Topic 2 - Seismic Retrofit of Bridges and Structures
Review of Retrofitting Methods and Programming

Brief history, current program, and guidance

Akiko Hiroe, CAESAR, PWRI

History of Seismic Design in Japan

Earthquakes

1923 **Great Kanto EQ. (M7.9)**

1964 **Niigata EQ. (M7.5)**

1978 **Miyagi-ken Oki EQ. (M7.1)**

Seismic Design Specifications

1924 Seismic Design was Introduced
1939 Seismic Coefficient Method

Seismic Force $F = W \times k_h$ k_h: Seismic Coefficient

1971 **Seismic Design Specifications**

- Effect of soil liquefaction was considered.
- Unseating Prevention Device was introduced.

1980 **Design Specifications for Bridges**

- Introduction of Ductility Design Concept
- Design Details (Re-bar Arrangement) for RC Columns

1990 **Design Specifications for Bridges**

- Two Level Seismic Design Concept
- Detailed Ductility Design Method for RC Columns

History of Seismic Design in Japan

Earthquakes

1995 **Hyogo-ken Nanbu (Kobe) EQ. (M7.3)**

Seismic Design Specifications

1996 Design Specifications for Bridges

- Introduction of inland near-field earthquake motion
- Introduction of ductility design alongside the seismic coefficient method for key structural components.
- Revision of dynamic analysis specifications to predict nonlinear structural behavior during earthquakes and setting of Input earthquake motions for dynamic analysis..
- Revision of liquefaction assessment methods and design approaches
- Introduction of lateral spreading due to liquefaction treatment
- Introduction of seismic isolation design method considering force distribution and damping.
- Advancement of RC pier and steel pier design methods
- Introduction of seismic design method for foundations based on the ductility design method
- Introduction of seismic design methods for various types of bearing supports
- Clarification of the functions of the unseating prevention system and specification of their design loads and methods

2002 Design Specifications for Bridges

- Aiming for performance-based technical standards
- Introduction of seismic performance 1-3
- Setting the limit states
- Utilization of dynamic analysis

History of Seismic Design in Japan

Earthquakes

2011 **The 2011 off the Pacific coast of Tohoku EQ. (M9.0)**

2016 **Kumamoto EQ. (M6.2 & 7.0)**

Seismic Design Specifications

2012 Design Specifications for Bridges

- Revision of design seismic motion
- Stating the basic requirements for components that are significantly affected by earthquakes
- Advancement of evaluation method of limit states for RC piers and steel piers
- Revision of unseating prevention system and clarification of their roles
- Addition of consideration for Tsunami

2017 Design Specifications for Bridges

- Clarification of positioning in the performance verification system
- Standardization of dynamic analysis
- Addition of consideration of fault displacement and ground deformation

Seismic Inspection in Japan begun from 1971

Seismic vulnerability inspection

(Bridge, Tunnel, Embankment, Utility Ducts, Rock/Snow Shed)

- **The first inspection in 1971 was triggered by the San Fernando Earthquake, USA**
- **Implemented by government notification**
- **6 times 1971, 1976, 1979, 1986, 1991 and 1996**
- **Targeted roads and inspection items were expanded sequentially due to the damage caused by the earthquake and the growing demand for earthquake countermeasures.**
- **Seismic reinforcement was mainly focused on matters cause critical effects.**

History of Seismic vulnerability inspection

year	The triggered incident	Main Target	Subject of retrofit
1971	San Fernando EQ	•All sections designated as General National Highways or higher •Other parts of road (Bridge length≧5m)	•Damage, settlement, or other deformation •Bearing edge distance of pile bent piers
1976		•All sections designated as General National Highways or higher •Other parts of road (Bridge length≧15m, Overpass)	•Damage, settlement, or other deformation •Bearing edge distance and unseating prevention device **Add measures against bridge collapse**
1979	Izu Ōshima EQ (Jan1978) Miyagi-ken Oki EQ (Jun 1978)	•All sections of roads designated as major prefectural roads or higher •Other parts of road (Bridge length≧15m, Overpass) **Expansion of target bridges**	•Damage, settlement, or other deformation •Unseating prevention device •Effects of liquefaction •Bearing capacity of soil and pile foundations •Strength of RC piers •Old foundation structures with low earthquake resistance **Add the viewpoint of effects of soil and strength of structure**

year	The triggered incident	Main Target	Subject of retrofit
1986	Urakawa-oki EQ (Mar 1982) Sea of Japan EQ (May 1983) Nagano EQ (Sep 1984) and Growing demand for earthquake resistance measures	•All sections of roads designated as major prefectural roads or higher •Other parts of road (Bridge length≧15m, Overpass)	•Damage, settlement, or other deformation •Unseating prevention device •Effects of liquefaction •Strength of RC piers (bottom and cut-off position) •Bearing capacity of pile foundations •Old foundation structures with low earthquake resistance **Focus on Strength of bottom and cut-off position of RC piers**
1991	**Trigger:** **Standard revised in 1990** **Seismic resistance for new bridge was improved**	•All sections of roads designated as major prefectural roads or higher •Other parts of road (Bridge length≧15m, Overpass)	•Damage, settlement, or other deformation •Unseating prevention device •Effects of liquefaction •Strength of RC piers (cut-off position) •Old foundation structures with low earthquake resistance
1996	Hyogo-ken Nanbu EQ (Jan 1995) **Focus on bridges with particularly high impact**	•All sections designated as General National Highways or higher •Other important section of road(overpass, important bridge)	•RC piers built before 1980 •Unseating prevention structure **In Hyogo-ken Nanbu EQ ,** **•RC piers built before 1980 suffered damage** **•Superstructure fell**

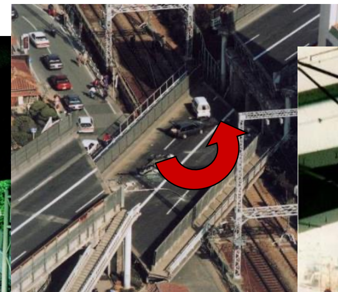
Bridge Damage in past earthquakes

Damage to low-stiffness areas like RC bridge piers or bearing area

Falling Gerber girder

Guide Specifications for reconstruction and repair 1995

1995／1／17 Hyogo-ken Nanbu (Kobe) Earthquake



1995／2／27
Guide Specifications for reconstruction and repair of highway bridges which suffered damage due to the Hyogo-ken Nanbu Earthquake (Fukkyu Shiyou)

Those Specifications issued how to rebuild and reinforce bridges so that it can withstand the Kobe Earthquake with ground motion.

After 1995 Kobe EQ., seismic retrofit of bridge columns and unseating prevention system has been conducted.

3-Year Seismic Retrofit Program (2005-2007)

- Purpose

  Prevention of Total Collapse / Deck Unseating

  →Save lives and Prevent irreparable damage

- Target Bridges

  1) Bridges on designated emergency network
  - **To prevent bridge collapse**
  - **Bridges designed by Pre-1980 design codes**

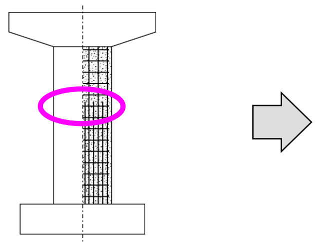
  2) Bridges over shinkansen and expressway
  - **To prevent secondary damage**

  3) Long-span bridges and non-typical girder bridges

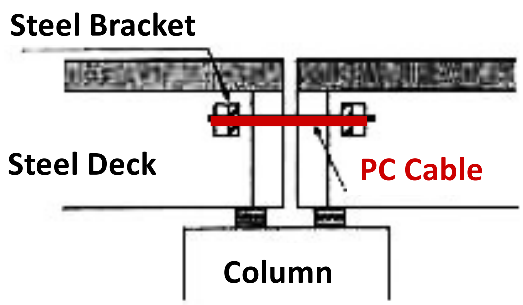
  (Truss bridges, arch bridges, cable-stayed bridges, suspension bridges)
  - Vulnerability study using dynamic analysis

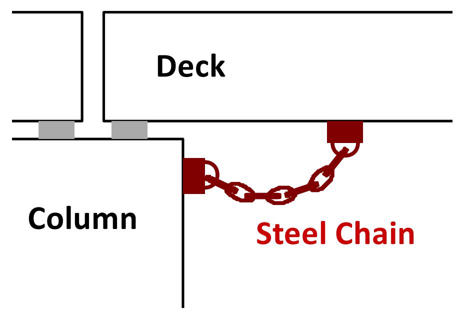
3-Year Seismic Retrofit Program (2005-2007)

Cut-off of longitudinal reinforcement

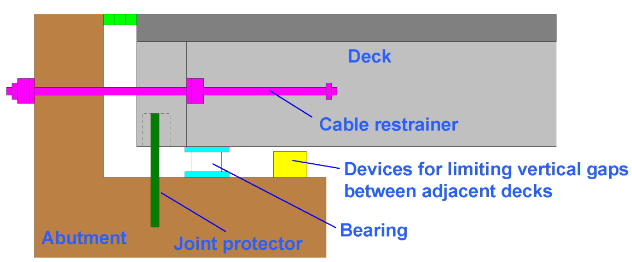


Unseating Prevention Device

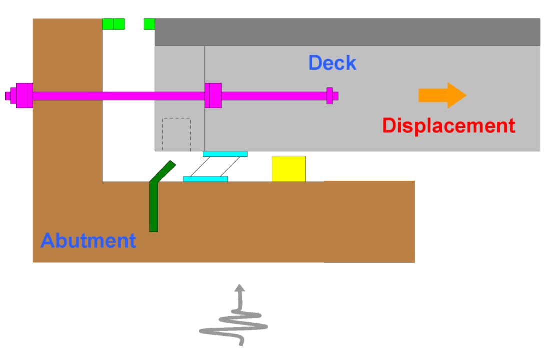




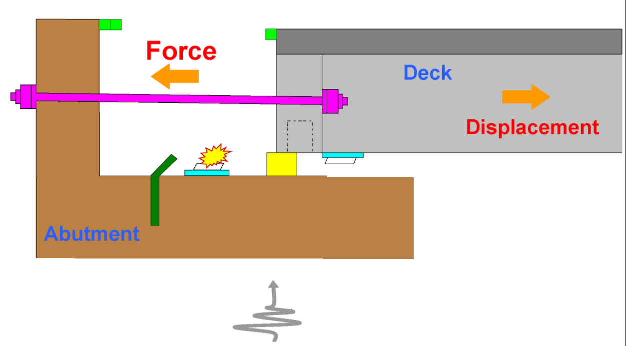
3-Year Seismic Retrofit Program (2005-2007)
Unseating prevention system



Schematic of unseating prevention system

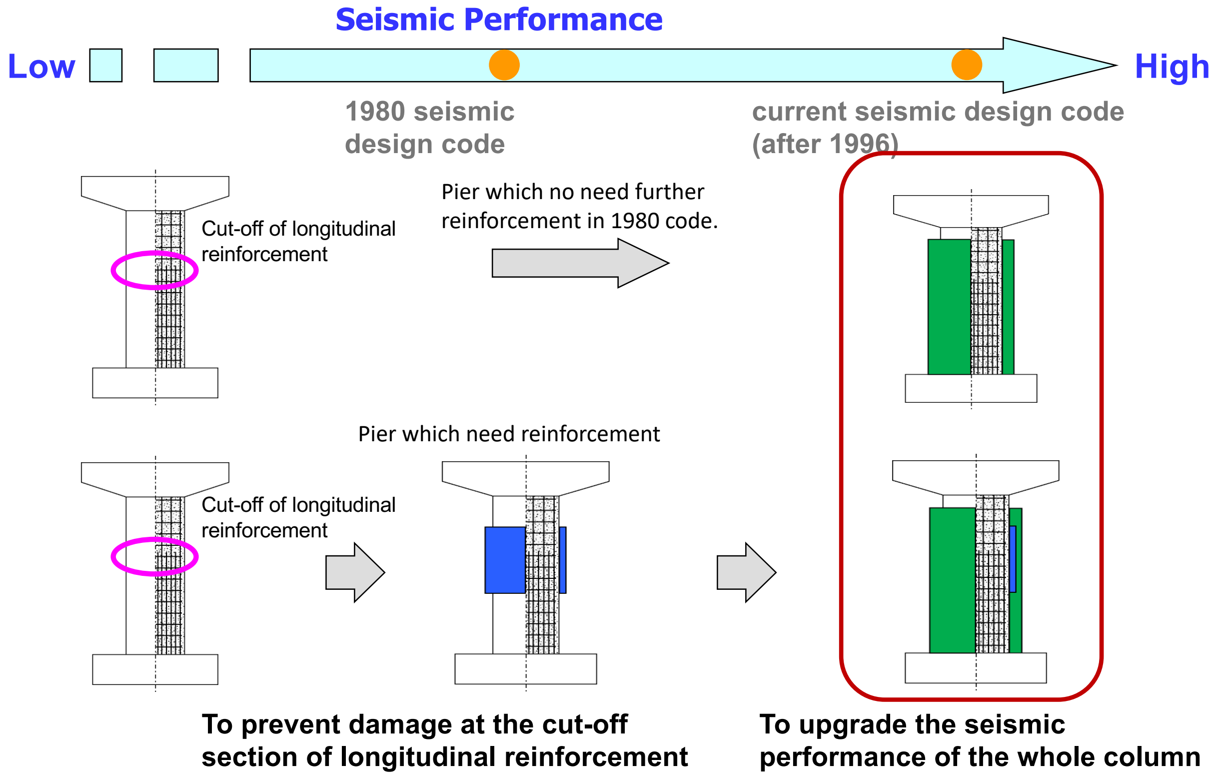


Expected earthquake (Level II)



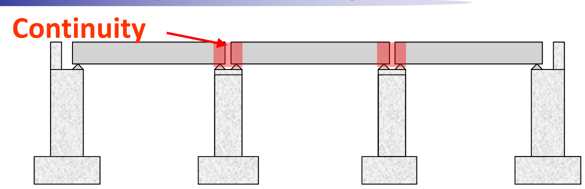
Unexpected large earthquake

Seismic Retrofit Measures Considering Entire Bridge Behavior 2008～ expressways and national highways and overpass

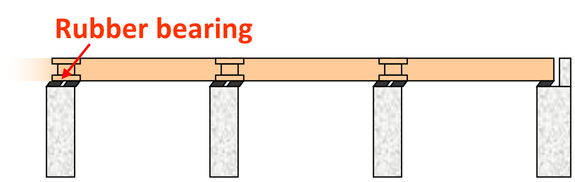


Seismic Retrofit Measures Considering Entire Bridge Behavior 2008～ expressways and national highways and overpass

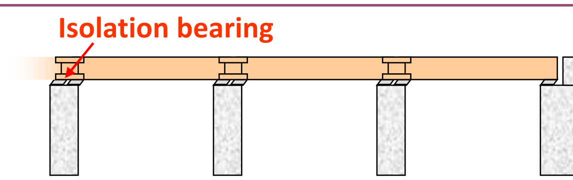
Continuity of superstructure



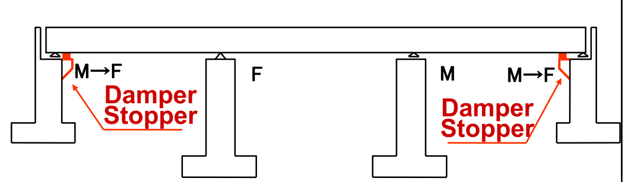
Distributing seismic force to other columns/abutment (using rubber bearing)



Seismic isolation design for reducing seismic force (using isolation bearing)



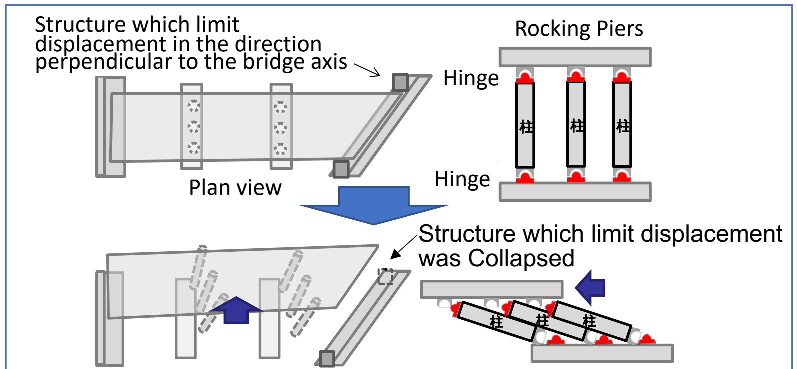
Using damper stopper to distribute seismic force to abutments



Retrofitting in response to significant damage on recent earthquakes

Collapse of the bridge over a highway in Kumamoto EQ, 2016

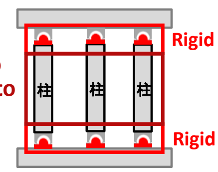
- The Bridge had rocking piers
- The piers could not stand alone
- They could not support horizontal superstructure inertia forces



Mechanism of Collapse of the bridge

➡ **Reinforcement to make the piers self-stable**

RC wrapping to convert pier into wall pier



Source: Materials of the 5th Meeting of Road Technology Subcommittee(MLIT)

Recent Seismic Retrofit in Japan

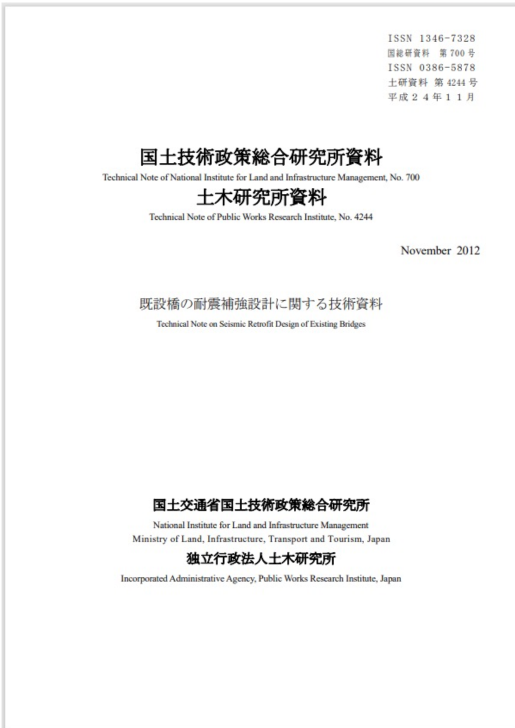
Since the 2002 revision of the standard, the concept of performance has been introduced into seismic design.

⬇

Performance must also be considered in seismic retrofitting

- In principle, existing bridges should have the same performance as newly constructed bridges.
- However, seismic retrofitting of existing bridges cannot be done in the same way as for newly constructed bridges

Technical Note on Seismic Retrofit Design of Existing Bridge


ISSN 1346-7328
国総研資料 第 700 号
ISSN 0386-5878
土研資料 第 4244 号
平成２４年１１月

国土技術政策総合研究所資料
Technical Note of National Institute for Land and Infrastructure Management, No. 700
土木研究所資料
Technical Note of Public Works Research Institute, No. 4244

November 2012

既設橋の耐震補強設計に関する技術資料
Technical Note on Seismic Retrofit Design of Existing Bridges

国土交通省国土技術政策総合研究所
National Institute for Land and Infrastructure Management
Ministry of Land, Infrastructure, Transport and Tourism, Japan
独立行政法人土木研究所
Incorporated Administrative Agency, Public Works Research Institute, Japan

Technical Note of National Institute for Land and Infrastructure Management, No.700, Nov 2012

https://www.nilim.go.jp/lab/bcg/siryou/tnn/tnn0700pdf/ks070001.pdf
(Japanese only)

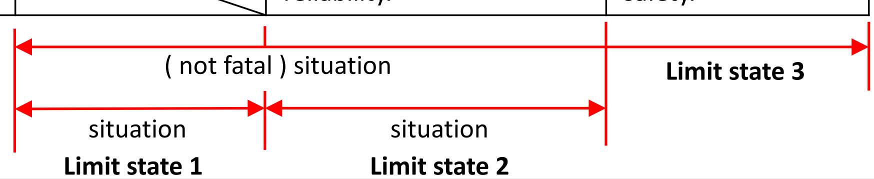
This content provides examples of perspectives that administrators consider when establishing seismic performance.

- The expected performance of the route (including the bridge) after earthquakes as part of the road network
- The need to prevent serious impact on other structures or facilities
- The difficulty of restoring functionality given the structural and construction conditions if the bridge is damaged

Basic concept of current specifications for highway bridges in Japan

Performance matrix

Situation \ Status	Condition of the bridge, primarily from a **function**		Condition of the bridge from a **structural safety**
	The condition in which the bridge's ability to support loads as a bridge is not impaired	The bridge's load-bearing capacity is partially degraded, but it is still within the range of the bridge's capacity to support the preliminarily assumed loads.	Not a fatal condition.
Dominated by permanent action and variable action	state with the required reliability.		Ensure the required safety.
Dominated by accidental action		state with the required reliability.	Ensure the required safety.



The level of seismic performance of bridges to be targeted in seismic retrofitting of existing bridges and corresponding considerations

From Technical Note of NILIM, No.700

	seismic performance of bridges to be targeted in seismic retrofitting	Safety in seismic design	Serviceability in seismic design	Restorability in seismic design	
				Short term	Long term
High	• Damage caused by level 2 earthquake motion is limited • The bridge is considered to be in a condition where its function can be restored promptly.	Ensures safety to prevent bridge collapse	Ensure rapid restoration of bridge functionality after an earthquake	Repairs for function recovery can be carried out through emergency restoration	Permanent restoration can be carried out relatively easily
↑	• There are parts of the bridge that will be damaged by level 2 earthquake motion • Permanent restoration will not be easy • The bridge is considered to be in a condition where its function can be restored promptly	Ensures safety to prevent bridge collapse	Ensure rapid restoration of bridge functionality after an earthquake	Repairs for function recovery can be carried out through emergency restoration	Permanent restoration is possible
Low	• The bridge is considered to prevent serious damage such as bridge collapse due to level 2 earthquake motion	Ensures safety to prevent bridge collapse	---	---	---

Performance is not completely equal to that of a newly constructed bridge

Other Points of Recent Seismic Retrofit in Japan

- While reinforcement will be provided directly for catastrophic damage, improvement measures is considered from a comprehensive perspective, including non-structural measures.
- The seismic reinforcement method is considered comprehensively, including mitigation costs, life-cycle costs (LCC), and replacement planning.
- There are no set measures against tsunamis or slope failures. Measures is considered on an individual basis, taking into account the performance of the road network.

Latest Initiatives: Lessons from 2024 Noto Peninsula Earthquake



Structural members designed to restrain displacement of superstructures were damaged by earthquake

➡
- It took a long time to repair the road and make it passable.
- When a series of large earthquakes occur, it may become impossible to restrain displacement of superstructures.

In the next revision of the Specification for highway bridges, the following measures will be added

- **Considering the possibility of repeated earthquakes, structures can be installed to restrain displacement of the superstructure in the vertical or horizontal direction.**
- **The considerations for installation include the potential for significant displacement, impact on road functionality, and ease of restoration.**

In response to this revision, the need for seismic retrofit of existing road bridges of high importance will be individually examined in the near future.

Performance of Retrofit Measures in Actual Events and Challenges in Recent Events

Jinsei KUWANO
Public Works Research Institute

Presentation flow

- **Backgrounds**

- **Ordinally Retrofit method in Japan**

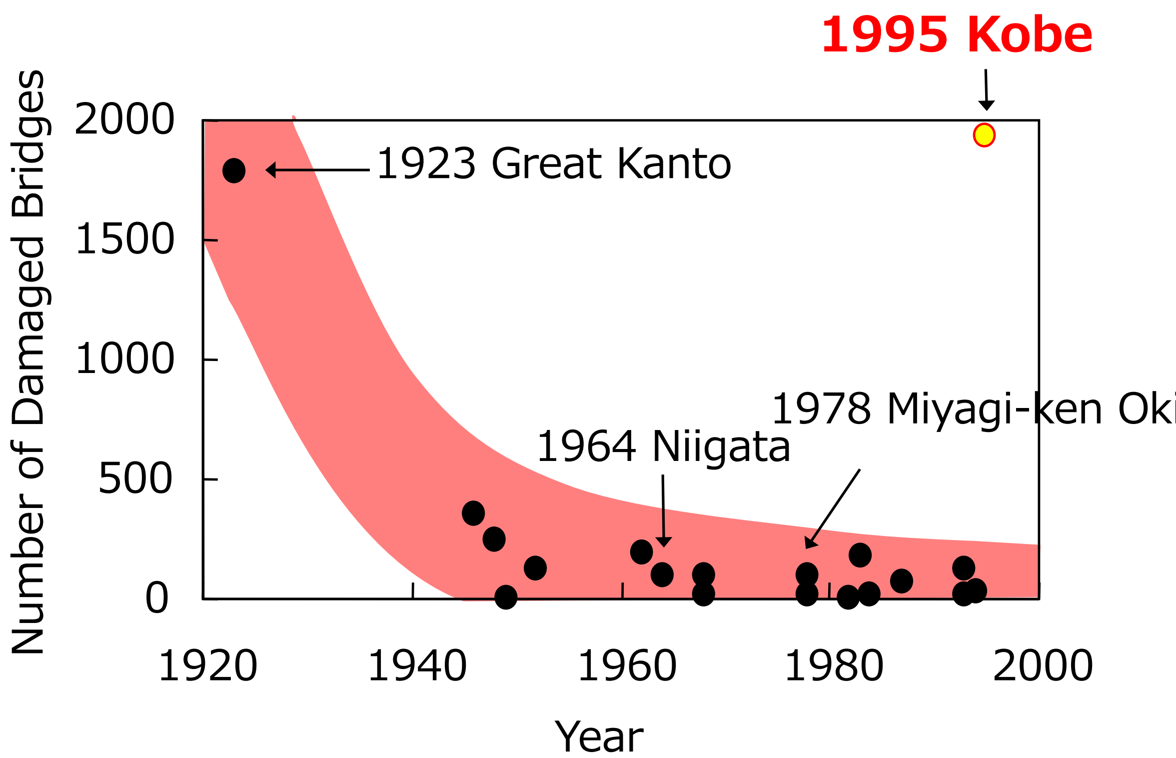
1. RC Jacket
2. FRP Jacket
3. Unseating prevention device
4. Lateral Displacement Confining Devices

- **Examples of damage caused by actual earthquakes**

1. 2011 Tohoku earthquake
2. 2016 Kumamoto earthquake
3. 2022 Fukushima earthquake
4. 2024 Noto peninsula earthquake

- **Conclusion**

Background



Background

□1995 Great Hanshin-Awaji Earthquake



- **Insufficient Seismic Performance** of Reinforced Concrete Columns
- Damage of **Unseating Prevention Devices**

■ Purpose

Prevention of Total Collapse / Deck Unseating

→Save lives and Prevent irreparable damage

Background

- In Japan, lessons learned from repeated earthquakes have been reflected in technical standards.
- For example, in the 1995 Great Hanshin-Awaji Earthquake, damage to reinforced concrete bridge piers was observed, prompting a surge in seismic retrofitting efforts.

- This time, we will explain how these seismically reinforced bridges performed in subsequent earthquakes. Here, we will show both good and bad examples and discuss future challenges.

Presentation flow

□ **Backgrounds**

□ **Ordinally Retrofit method in Japan**

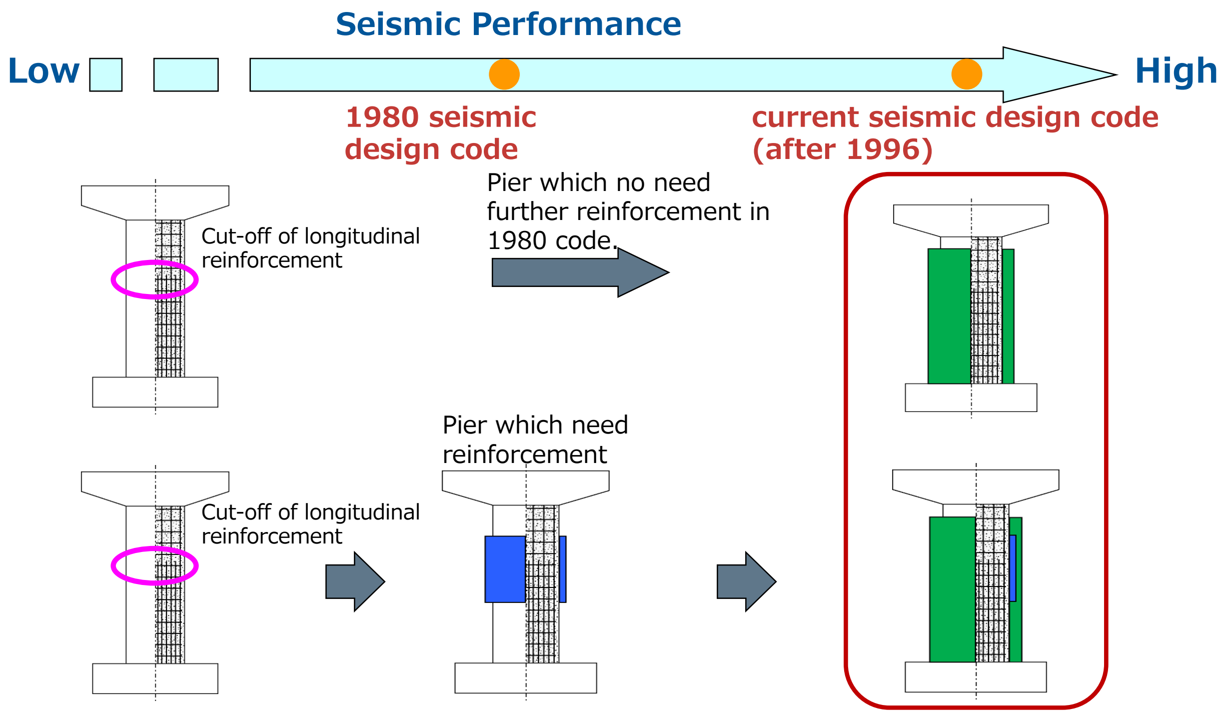
1. **RC Jacket**
2. **FRP Jacket**
3. **Unseating prevention device**
4. **Lateral Displacement Confining Devices**

□ **Examples of damage caused by actual earthquakes**

1. **2011 Tohoku earthquake**
2. **2016 Kumamoto earthquake**
3. **2022 Fukushima earthquake**
4. **2024 Noto peninsula earthquake**

□ **Conclusion**

Retrofit method（RC Jacket）



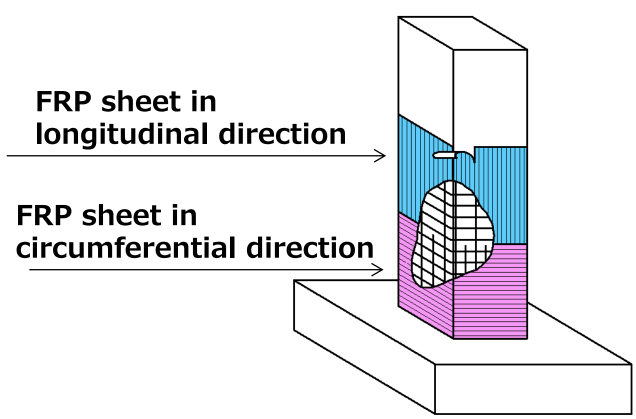
To prevent damage at the cut-off section of longitudinal reinforcement

To upgrade the seismic performance of the whole column

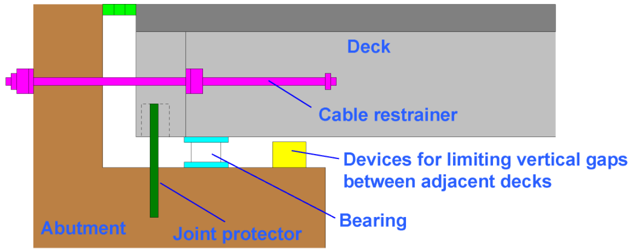
Retrofit method（FRP Jacket）

FRP Jacketing

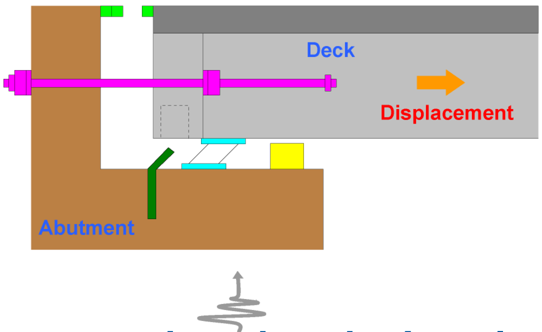
FRP: Fiber Reinforced Plastic



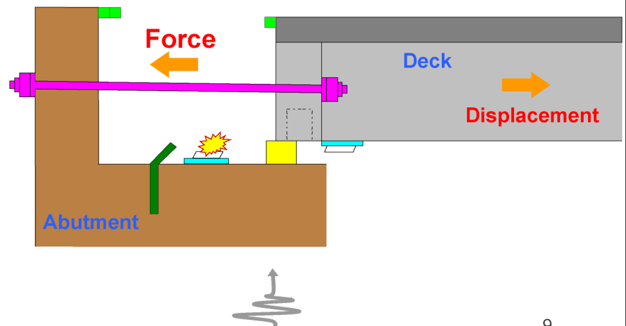
Retrofit method（Unseating prevention device）



Schematic of unseating prevention system

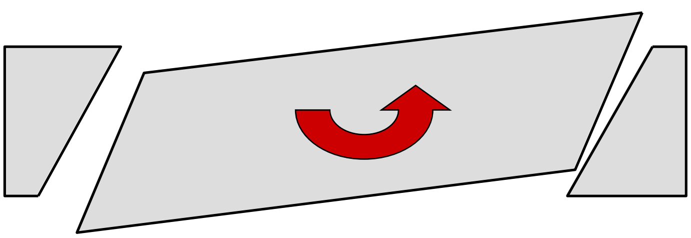


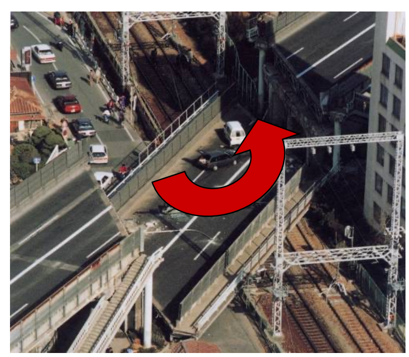
Expected earthquake (Level II)

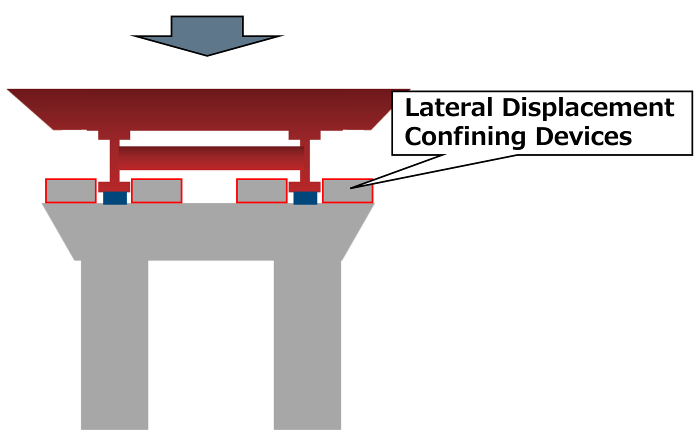


Unexpected large earthquake

Retrofit method(Lateral Displacement Confining Devices)







Presentation flow

□ Backgrounds

□ Ordinally Retrofit method in Japan

1. RC Jacket
2. FRP Jacket
3. Unseating prevention device
4. Lateral Displacement Confining Devices

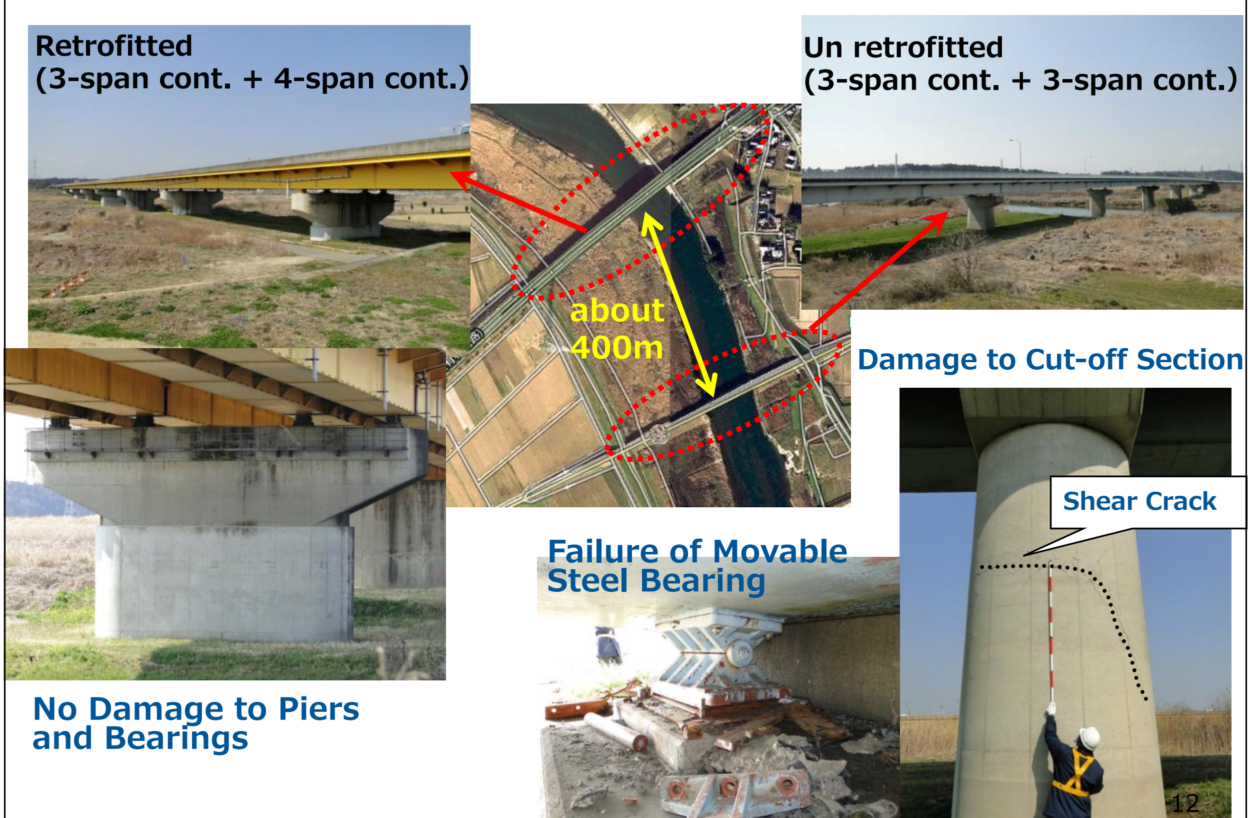
□ Examples of damage caused by actual earthquakes

1. 2011 Tohoku earthquake
2. 2016 Kumamoto earthquake
3. 2022 Fukushima earthquake
4. 2024 Noto peninsula earthquake

□ Conclusion

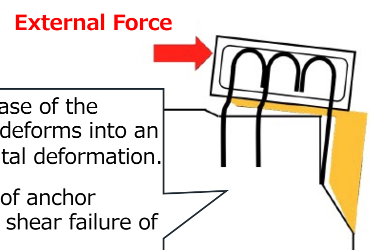
1. 2011 Tohoku earthquake

https://www.nilim.go.jp/lab/bbg/saigai/h23tohoku/houkoku/happyou/2-7.pdf



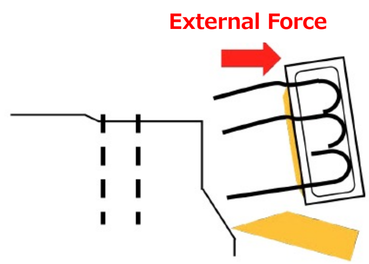
2. 2016 Kumamoto earthquake

- There were cases where Lateral Displacement Confining Devices were destroyed and bridges collapsed.
- Although there are various factors involved, damage to Lateral Displacement Confining Devices is also considered to be a factor in bridge collapse.



After pulling out, the base of the anchor reinforcing bar deforms into an S shape due to horizontal deformation.

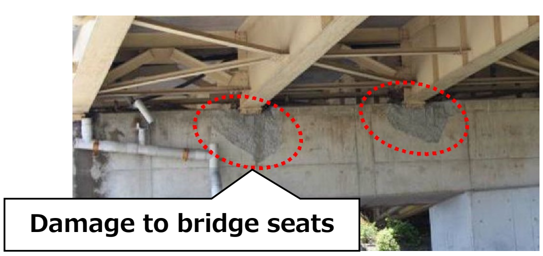
S-shaped deformation of anchor reinforcing bars due to shear failure of concrete



Takahashi et.al, DAMAGE OF LATERAL DISPLACEMENT CONFINING DEVICES OF BRIDGES CAUSED BY THE 2016 KUMAMOTO EARTHQUAKE AND ESTIMATION OF FAILURE MECHANISM, https://doi.org/10.2208/jscejseee.74.I_45

2. 2016 Kumamoto earthquake

- This is an example of wrapping that was carried out during the 2016 Kumamoto Earthquake. Although no damage was observed in the columns due to the wrapping, damage was observed in other parts.



3. 2022 Fukushima earthquake

- Damage to bearings (Fukushima) After the 2021 earthquake, pins broke in multiple bearings. Subsequently, the bearings were replaced for restoration, but the 2022 earthquake caused similar damage.

P1（Move）
Possibility of pin breakage or pin loosening

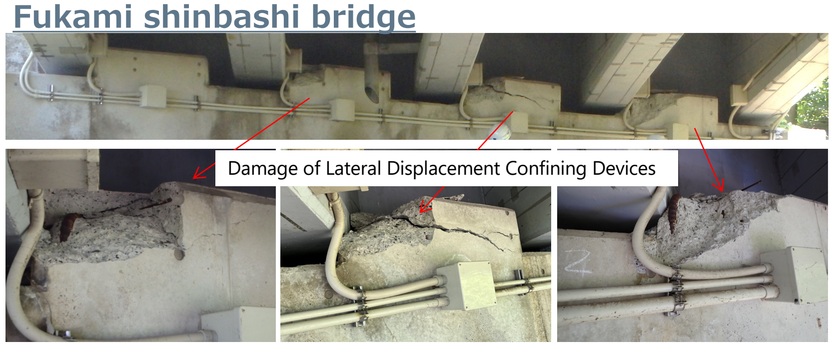
P3（Discrepancy department、Move）
Possibility of pin breakage or pin loosening

4. 2024 Noto peninsula earthquake

- In the Noto Peninsula earthquake, there were many cases where Lateral Displacement Confining Devices were damaged.
- In addition, not only were lateral displacement restraint structures damaged, but in some cases, the main girders were also fatally damaged.

Ukai Ohashi bridge

Fukami shinbashi bridge



4. 2024 Noto peninsula earthquake

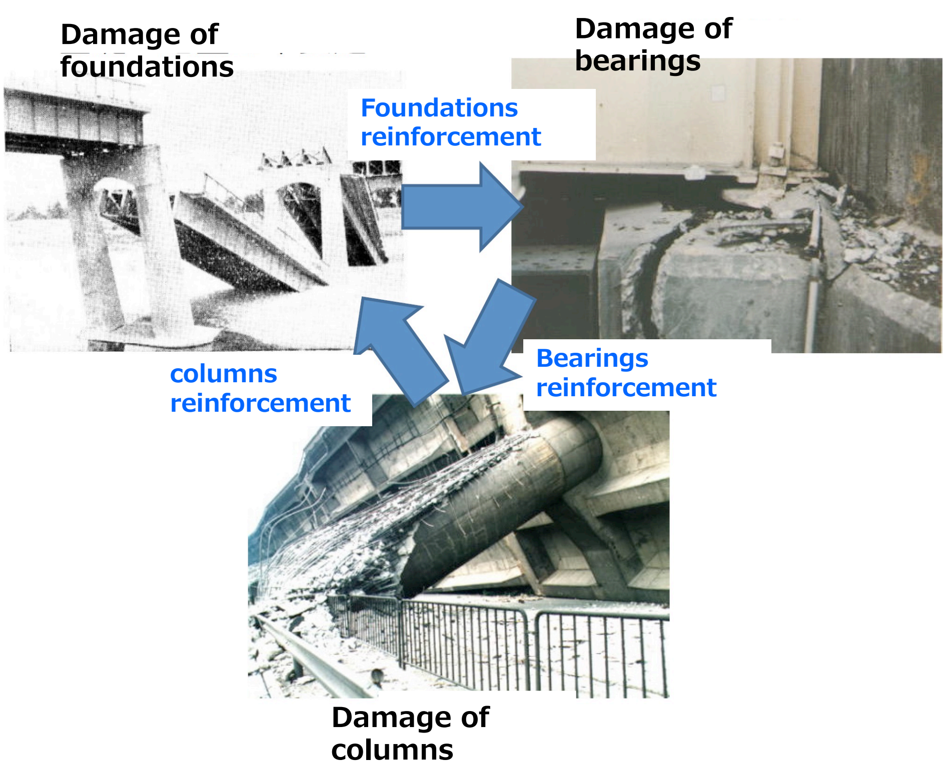
- while the reinforcement measures were effective, there were cases where damage occurred in other parts of the structure.

□ In 2007

2007 年能登半島地震で被災を受けた能登島大橋 RC 橋脚の被害について
http://library.jsce.or.jp/Image_DB/eq04-07/proc/02002/2010-0029.pdf

□ In 2024

Challenges in Recent Events



Presentation flow

- Backgrounds

- Ordinally Retrofit method in Japan

1. RC Jacket
2. FRP Jacket
3. Unseating prevention device
4. Lateral Displacement Confining Devices

- Examples of damage caused by actual earthquakes

1. 2011 Tohoku earthquake
2. 2016 Kumamoto earthquake
3. 2022 Fukushima earthquake
4. 2024 Noto peninsula earthquake

- Conclusion

Conclusion

- The seismic reinforcement of RC piers retrofitted performs well.

- It is necessary to enhance knowledge regarding the installation location of Lateral Displacement Confining Devices. It is also necessary to take care not to damage the main girders.

- In the case of seismic reinforcement, although no damage occurs at the reinforced location, damage occurs in other parts.

- There are areas that become relatively weak when other areas are strengthened, so damage tends to concentrate in those areas. Therefore, when reinforcing, it is necessary to anticipate where damage will occur due to an earthquake.

Topic 2-B
Target Seismic Performance and Field Observations

Seismic Retrofit of Bridges and Structures

Target Seismic Performance and Field Observations Brief Presentations

- Performance of retrofit measures in actual events and challenges in recent events (Jinsei KUWANO)
- Unmet performance needs (Tony YOON)

Target Seismic Performance and Field Observations
Discussion

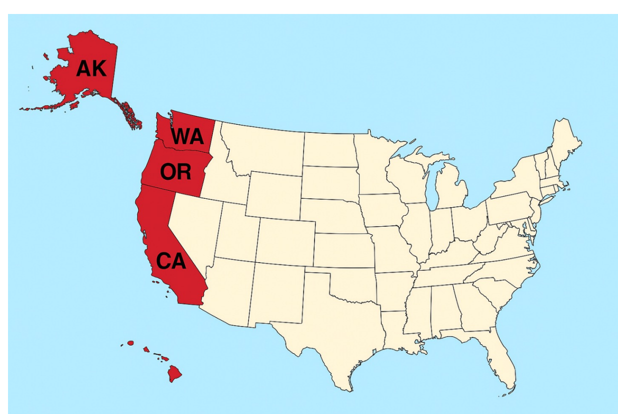
1. Damages observed on retrofitted structures and impact to post-event transportation
2. Below-ground retrofit and observed performance
3. Field performance observation and new recommendations for
   - Retaining structures
   - Abutments
   - Embankments
   - Slopes
   - Drainage

- Improved retrofit recommendations for
  - Moisture control (reducing liquefaction)
  - Slope stabilization
  - GRS/MSE for approach embankment
  - Steep slope at abutment

State Level Observations - Retrofitted Bridge Performance

Bridges in seismically active west coast states - AK WA OR & CA - have been continuously retrofitted since late 1980s. These retrofitted bridges have experienced only a limited number of significant earthquakes.

The following slides present past retrofit efforts and the reported performance of retrofit bridges in each state.



State Level Observations - Retrofitted Bridge Performance

Alaska

Alaska Retrofitting Performance and Unmet Needs

- Limited experience with retrofit performance; even the 2018 M7.1 Anchorage Earthquake was not large enough to engage any previously installed retrofits in area.
  - Cable restrainers were used as retrofit measure and remain in service; however, other measures are now recommended instead.

Alaska Retrofitting Performance and Unmet Needs

- Most failures in 2018 M7.1 Anchorage Earthquake were geotechnical

Alaska Retrofitting Performance and Unmet Needs

- Most of the ‘easy’ bridges have received Phase 1 retrofits (seat widening, etc.)
- The remaining bridges do not always have straight forward solutions and require focused research and solutions. These retrofits become exceeding expensive and could consume nearly all our retrofit budget.

Figure 3.63: Knee joint test setup for Test 2 specimen (D/t = 44).

State Level Observations - Retrofitted Bridge Performance

Washington

WSDOT Seismic Retrofit Program

Limitations

- Minimizes but does not eliminate damage (Life Safety)
- Above-foundation only
- No liquefaction
- Does not guarantee full post-EQ operation
- Emergency repairs may be needed for emergency vehicles
- Limited budget – cost/benefit

Liquefaction Example
2001 Nisqually Earthquake

State Level Observations - Retrofitted Bridge Performance

Oregon

Seismic Performance of Retrofitted Bridges in Oregon

Oregon's seismic retrofit program is relativelyy new and it has not been tested yet by a significant EQ

Phase 1 Seismic Retrofit is incorporated in most rehabilitation project, unless the scope of work does not extend below the bridge deck.

Generally, the Phase 1 Seismic Retrofit consist of installation of cable restraints, shear keys, or beam seat lengthening/widening.

When feasible, the use of Buckling Restrained Braces (BRB) has been proven to be a very economical retrofit option.

Retrofitted Bridges in Oregon – Design and Construction Challenges

Oregon bridges that receive a Phase 2 Seismic Retrofit are expected to perform like new bridges ("Life Safety" under a 1000-year EQ and "Operational" after a major Cascadia Subduction EQ)

Retrofitting existing bridge foundation is always a challenge, manly due to vertical clearances, topography, or environmental constraints.

If driving new piles is not an option, a combination of footing enlargement and micropiles or footing anchors will be considered.

State Level Observations - Retrofitted Bridge Performance

California

Current Requirement for Seismic Retrofit of Bridges in CA

LRFD

MEMO TO DESIGNERS 20-4 • JUNE 2016

20-4 SEISMIC RETROFIT GUIDELINES FOR BRIDGES IN CALIFORNIA

Expected Performance

The primary performance standard for retrofitting bridges is to prevent the structure from reaching the collapse limit state[2] for the Design Earthquake[3]. The goal of this "No Collapse" performance standard is to protect human life and there are no serviceability expectations for retrofitted bridges.

An acceptable determination of collapse is captured through an analysis of the bridge model subject to the Design Earthquake. However, determining collapse is different than simply determining that demand exceeds capacity. First of all, capacity is more conservatively

Current seismic design philosophy is to No Collapse.

MTD 20-4 addresses
- -Roles and Responsibility
- -Seismic Hazard Types
  - Shaking
  - Liquefaction/Lateral Spreading
- -Seismic Vulnerabilities of Each Components

-Retrofit Measures
- Unseating Prevention
  - Catcher Block
  - Pipe Seat Extender
  - Cable Restrainer
- Shear Failure Prevention
  - Infill Wall
  - Steel (or FRP) Jacketing
- Confinement Improvement
  - Steel Column Casing

Past Retrofit Program

The Phase 1 and 2 seismic screenings of the 1990s resulted in the retrofit of about 2200 state bridges.

About 1000 local agency bridges during Phases 1 and 2 have also been retrofitted.

The screenings of 2015 and 2019 identified an additional 620 vulnerable state bridges. Some of them have been retrofitted.

Seismic Retrofit Program	Completed Bridges
Phase 1 Program	1039
Phase 2 Program	1154
Toll Bridge Program	9
Post-Phase 1 & 2 Retrofits	302
Total	2504

1. **Bridge Widenings**
   Caltrans requires Designers to evaluate existing bridges for seismic vulnerabilities during bridge modifications such as widenings, deck replacements, and other major rehabilitation work. A seismic retrofit is added to the project scope if these bridges do not meet the current seismic performance criteria. Thirteen bridges (Case 10) were retrofitted as part of a widening/rehabilitation project.

2. **Post Loma Prieta Bridge Screenings**
   The last 200 bridges remaining from the 1990's screening were added to the Structure Maintenance and Investigation Outstanding Work Recommendations (OWR) in 2000.

3. **Post 2000 Bridge Screenings**
   Smaller retrofit programs were initiated by Caltrans Office of Earthquake Engineering, Analysis and Research (OEEAR) in the 2000's. In 2003, bridges with short seats and/or inadequate restrainers were added to the OWR. In 2010, bridges with flared columns, bridges with unbalanced columns and bents, and bridges with shear-critical columns were added to the OWR.

4. **Continuous Bridge Screenings**
   More recently (in 2015), Caltrans bridge inventory was re-screened to identify bridges with increased ground shaking and/or other seismic hazards that were not considered in earlier retrofit programs. About 500 bridges were identified as being at considerable risk and 200 of these bridges that were at risk due to high ground shaking or large fault offsets were added to

Post-Earthquake Performance of Retrofitted Bridges

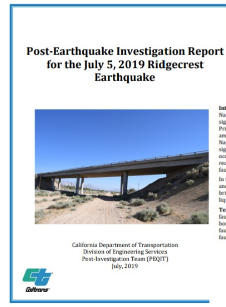
Major Seismic Events with Mw equal to or greater than 6.0

2014 South Napa (Mw 6.0)

2019 Ridgecrest (Mw 7.1)

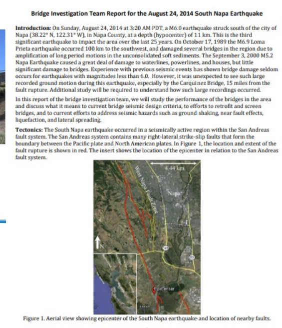
2021 Little Antelope Valley (Mw 6.0)
First use of UAS Inspections

2022 Ferndale (Mw 6.4)



Post-Earthquake Investigation Report for the July 5, 2019 Ridgecrest Earthquake

California Department of Transportation
Division of Engineering Services
Post-Investigation Team (PEQIT)
July, 2019



Bridge Investigation Team Report for the August 24, 2014 South Napa Earthquake

Introduction: On Sunday, August 24, 2014 at 3:20 AM PDT, a M6.0 earthquake struck south of the city of Napa (38.22° N, 122.31° W), in Napa County, at a depth (hypocenter) of 11 km. This is the third significant earthquake to impact the area over the last 25 years. On October 17, 1989 the M6.9 Loma Prieta earthquake occurred 100 km to the southwest, and damaged several bridges in the region due to amplification of long period motions in the unconsolidated soft sediments. The September 3, 2000 M5.2 Napa Earthquake caused a great deal of damage to waterlines, powerlines, and houses, but little significant damage to bridges. Experience with previous seismic events has shown bridge damage seldom occurs for earthquakes with magnitudes less than 6.0. However, it was unexpected to see such large recorded ground motion during this earthquake, especially by the Carquinez Bridge, 15 miles from the fault rupture. Additional study will be required to understand how such large recordings occurred.

In this report of the bridge investigation team, we will study the performance of the bridges in the area and discuss what it means to current bridge seismic design criteria, to efforts to retrofit and screen bridges, and to current efforts to address seismic hazards such as ground shaking, near fault effects, liquefaction, and lateral spreading.

Tectonics: The South Napa earthquake occurred in a seismically active region within the San Andreas fault system. The San Andreas system contains many right-lateral strike-slip faults that form the boundary between the Pacific plate and North American plates. In Figure 1, the location and extent of the fault rupture is shown in red. The insert shows the location of the epicenter in relation to the San Andreas fault system.

Figure 1. Aerial view showing epicenter of the South Napa earthquake and location of nearby faults.

1

Post Earthquake Investigations (PEQIT) were conducted, and the findings were documented after each event.

Post-Earthquake Performance of Retrofitted Bridges

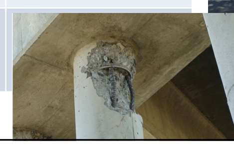
Based on the inspections, minor spalling or lateral movement was reported; however, no catastrophic failure was observed. Thus, the retrofitted bridges met the target performance criteria outlined in MTD 20-4. The inspection after each seismic event reports:

Post-Earthquake Performance of Retrofitted Bridges – Napa 2014




Bridge Name	Retrofit Details	Damage Observed	Repair Notes
Napa River Bridge (Route 37)	Steel jackets, prestressed diaphragms, pipe seat restrainers, additional piles	Expansion joints and joint seals damaged, railing shifted	JS strip replacement
Napa River BOH (Route 29)	Foundation strengthened with piles (1994)	6" x 6' spall at abutment with exposed rebar	Patch spall and replace wingwall
Old Sonoma Road OC	Cable restrainers (1980s), additional retrofit (1990s)	Curb and rail spalls, worsened by earthquake	Repair spalls and curbs
First Street OC	Cable restrainers	Deck overhang spalling at expansion joint, approach settlement	Patch spalled area
Napa Slough Bridge	Cable restrainers, bolsters, diaphragm strengthening	Pile extension spalls due to battered piles	

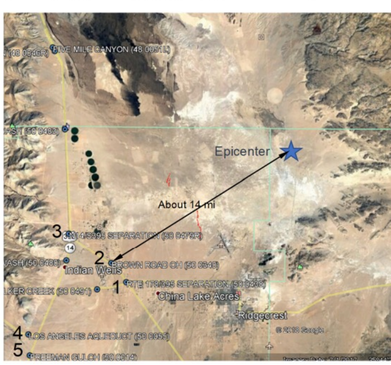


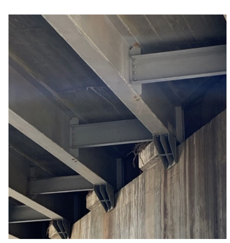
Post-Earthquake Performance of Retrofitted Bridges – Ridgecrest 2019

Bridge List for PEQIT investigation after Ridgecrest EQ Mw 6.4 & 7.1

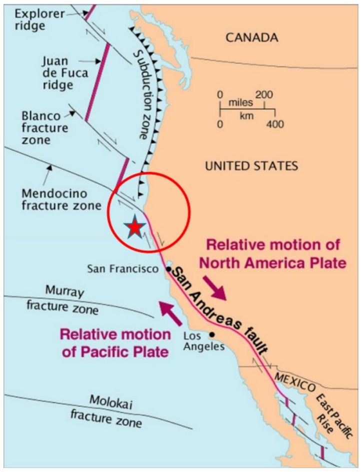
	Br No	Br Name	Route	PM
1	50 0438	178/395 Separation	178	R93.23
2	50 0340	Brown Rd OH	395	R25.08
3	50 0479R	N14/S395 Separation	14	64.54
4	50 0055	Los Angeles Aqueduct	178	87.67
5	50 0014	Freeman Gulch	14	56.[illegible]5






Post-Earthquake Performance of Retrofitted Bridges – Ferndale 2022



04 - 0134 EEL RIVER BRIDGE AT FERNDALE (FERNBRIDGE) ON HIGHWAY 211

Post-Earthquake Performance of Retrofitted Bridges – Ferndale 2022

04 - 0134 EEL RIVER BRIDGE AT FERNDALE (FERNBRIDGE) ON HIGHWAY 211

Drone Inspection 2025 Ferndale Earthquake

23

Retrofitted Bridge Performance

Open Discussion

24

Topic 2-C
Durability and Consideration of other Design/Maintenance Factors

Seismic Retrofit of Bridges and Structures

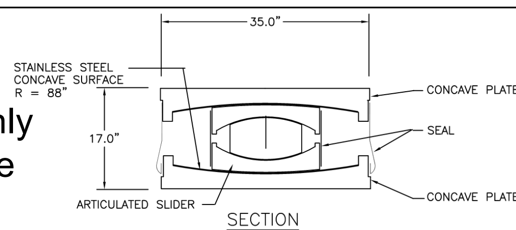
Durability and Consideration of other Design or Maintenance Factors Brief Presentations

- Deterioration of retrofit measures and non-seismic implication (Amy LELAND)
- Durability and Consideration of other Design or Maintenance Factors (Masahiro SHIRATO)

Durability and Consideration of other Design or Maintenance Factors Discussion

1. Durability issues for some retrofit measures impacting seismic performance in actual seismic event
2. Retrofit measures creating mechanical issues (local high stress, etc.) or maintenance issues to other bridge features
3. Mitigations that increase inspectability and serviceability of retrofit measures and bridge elements near seismic retrofit measures

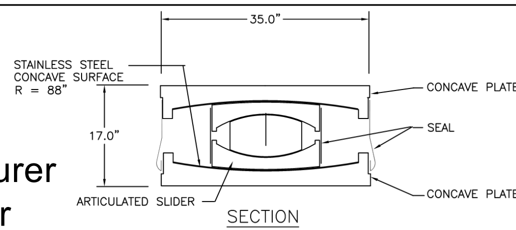
Durability – Bearings



- Friction pendulum bearings are commonly used to reduce forces into a substructure due to high seismic forces
  - Retrofit or new design
- Water and debris have been observed within the bearings


Durability – Bearings

- And, within the inner seal
- Testing was performed by the manufacturer showing that the contribution of the inner component was not required



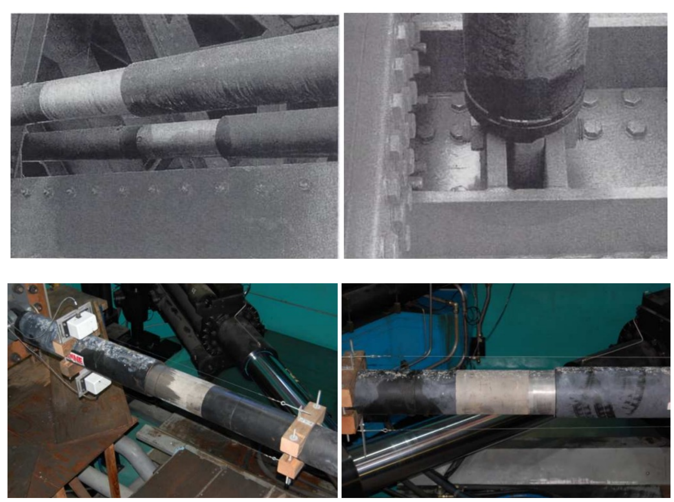
Alaska Bridge Retrofit Durability – Friction Pendulum Bearings

- Recently water and dirt was found to be entering our friction pendulum isolation bearings used in retrofit applications
- A research project was undertaken at the University of Nevada Reno to determine if this contamination (and ice in the winter) would affect the design characteristics of these bearings.
- Actual in-service bearings were removed and tested in an environmental chamber at -40°F.
- Changes in the friction coefficients were noted, but were within the realm of usual bounding practices thus validating the initial design assumptions.

Case Study: Viscous Damper Issues – Caltrans

- Several viscous dampers began leaking fluid shortly after installation (1998–2001)
- Leak points: threaded joints, internal seals, clevis pins
- Environmental exposure (dust, vibration, humidity) accelerated wear
- Protective covers failed – bolts sheared, components rusted
- Higher-than-expected ambient vibration contributed to early fatigue

Case Study: Viscous Damper Issues – Caltrans

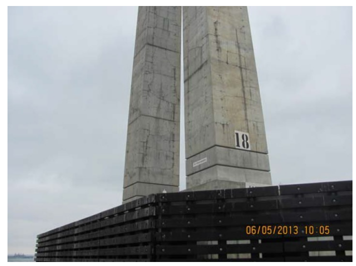


- Leakage did not always mean loss of damper function – some still met specs
- Six dampers were later replaced at other sites (e.g., Santiago Creek)
- Maintenance concerns led Caltrans to reconsider damper use
- Shift toward alternatives
- Emphasis on lifecycle reliability and ease of inspection

Case Study: Concrete Jacket Installation – Caltrans

In 2002, the existing columns were concrete-jacketed as a seismic retrofit measure.

The columns developed extensive cracking on all faces over the full height of the columns, which was believed to be due to temperature and shrinkage.

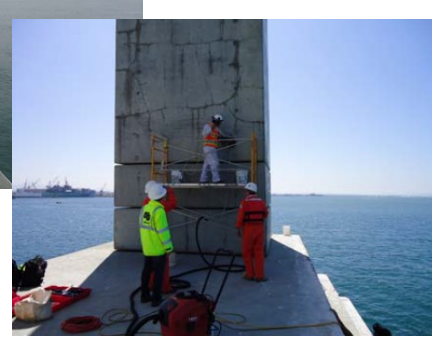


Case Study: Concrete Jacket Installation – Caltrans

In 2013, the concrete core sample taken by Caltrans Material Engineering & Testing Services (METS) for lab testing to ensure quality.

The evaluation included:

Chloride levels
Depth of visible cracks
Concrete quality
Condition of any reinforcement encountered



Oregon Bridges: Seismic Retrofit Performance

Extensive bridge vibration, coupled with environmental factors, can lead to pin assemblies of damping devices to become loose (or even fall off as in this case), making the efficiency of the protection system unpredictable.

Oregon Bridges: Seismic Retrofit Performance

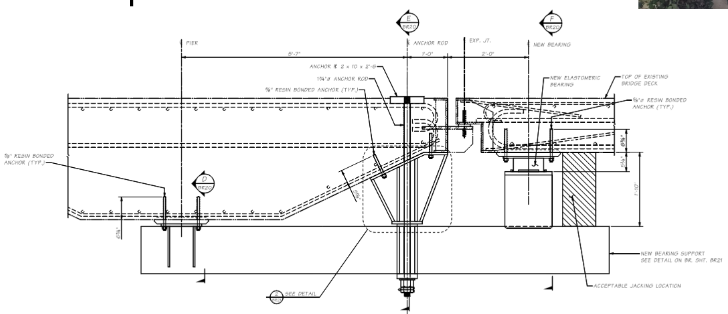
Installation of restrainer cables has been proven to be the most economical solution for preventing unseating of bridge spans. However, inspection and maintenance of these retrofit devices can be challenging.

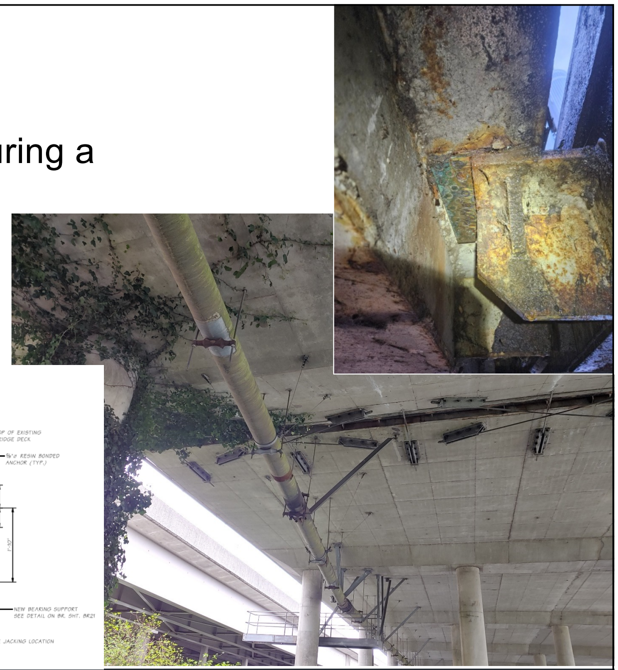
In marine environment, corrosion may lead to the need for full or partial replacement of cable assemblies.

In some bridge locations, environmental factors (e.g., high temperatures), can cause the external cables to experience extensive slack and lose part (or the entire) of their intended function.

Maintenance Factors

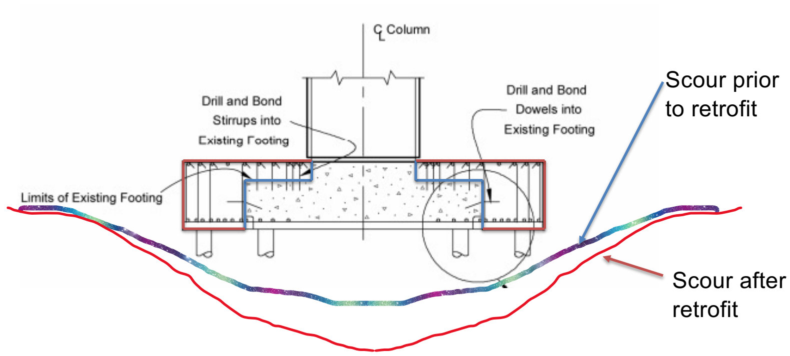
- Longitudinal restrainers installed during a Phase 1 retrofit
- Bearing seats need to be retrofitted
- Access difficult due to other bridge components





Design Factors

- Increasing foundation size increases scour depth



Design Factors

- If capacity protecting elements, increasing the capacity of the columns would require more capacity in the pier caps and footings

U.S. Department of Transportation
Federal Highway Administration

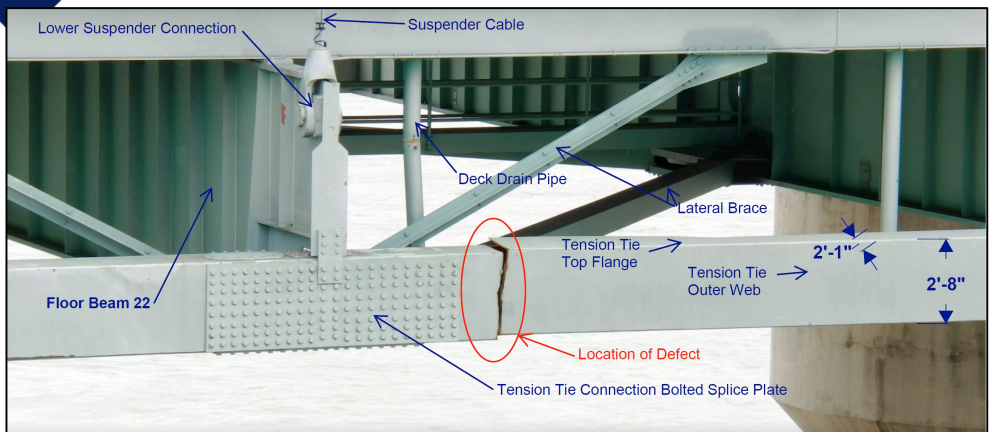
I-40 Mississippi River Bridge Seismic Retrofit

- Interstate 40, Tied Arch Bridge, Memphis, TN
  - Retrofitted with friction pendulum bearings
- Superstructure
  - Diaphragm / Cross Frame Replacement
  - Bottom Lateral Retrofit
  - Bearing Replacement – 112 bearings
  - Expansion Joint Replacement

Image: FHWA

U.S. Department of Transportation
Federal Highway Administration

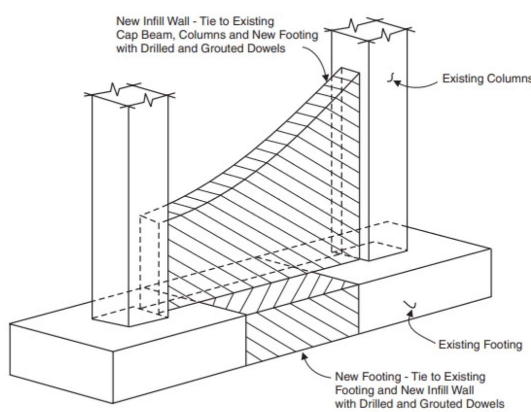
I-40 Mississippi River Bridge – Tie Girder Fracture (2021)



Source: Michael Baker International

Design Factors

- If adding fill walls, changes are made to the loading in the footings



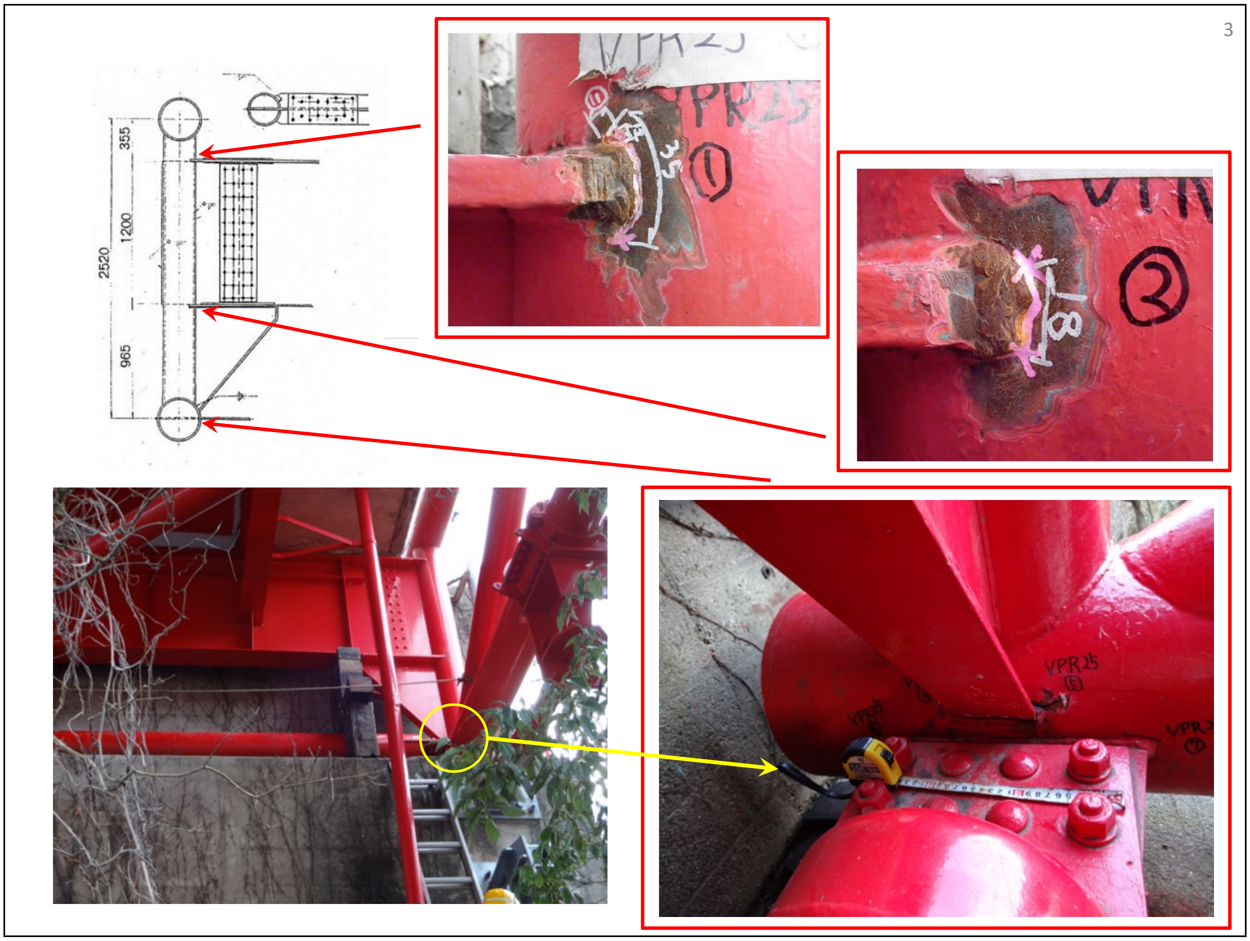
Deterioration and damage to seismically retrofitted bridges

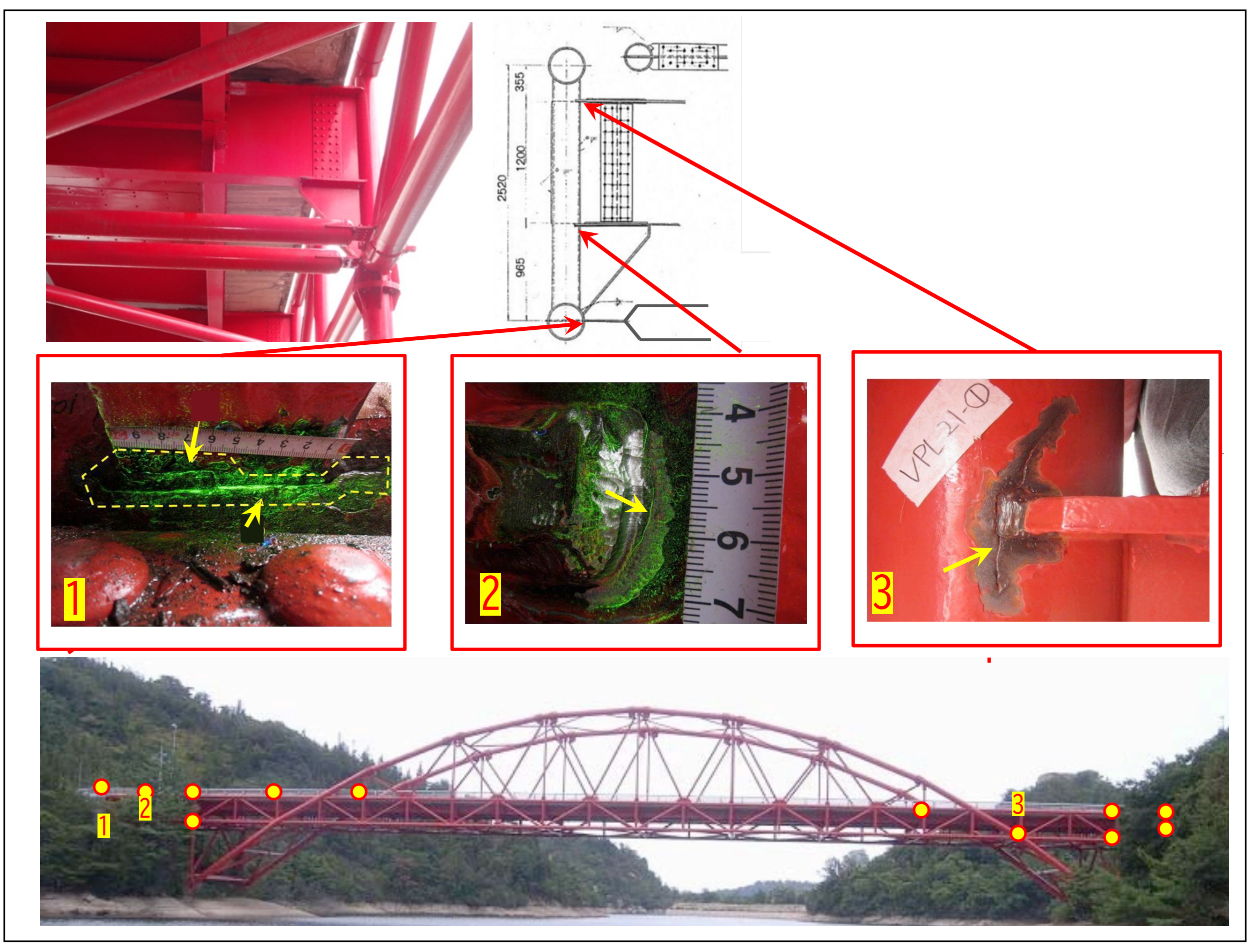
August, 2025

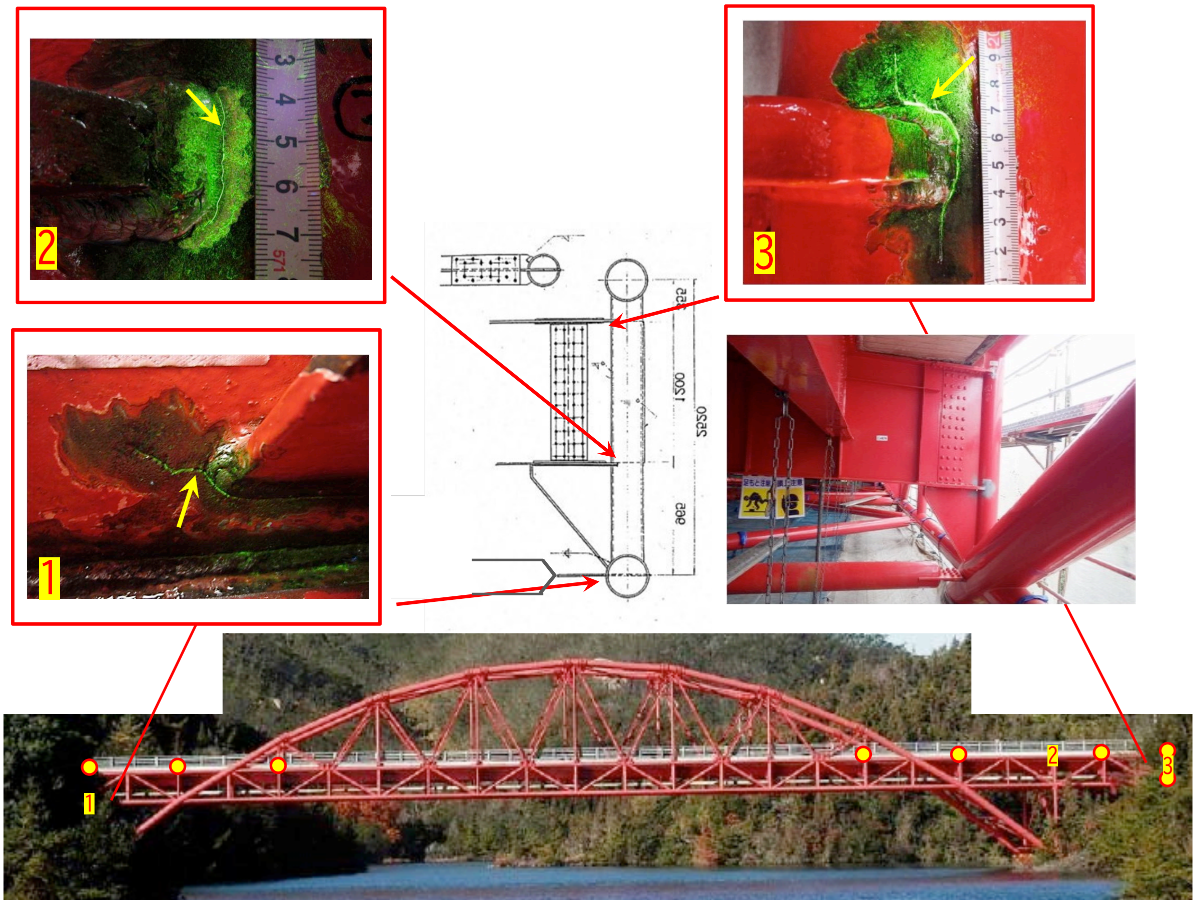
Masahiro SHIRATO
Bridge and Structures Division, NILIM, MLIT

Bridge A

- ✓ Steel arch bridge
- ✓ L = 110 m, ADT = 11,600, ADTT = 300

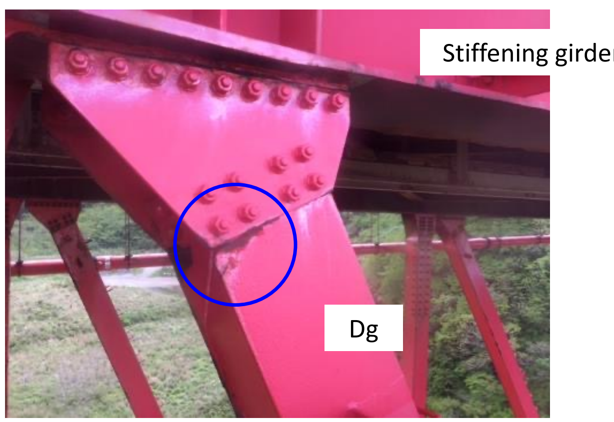

3
355
1200
2520
965
VPR25
①
35
②
18

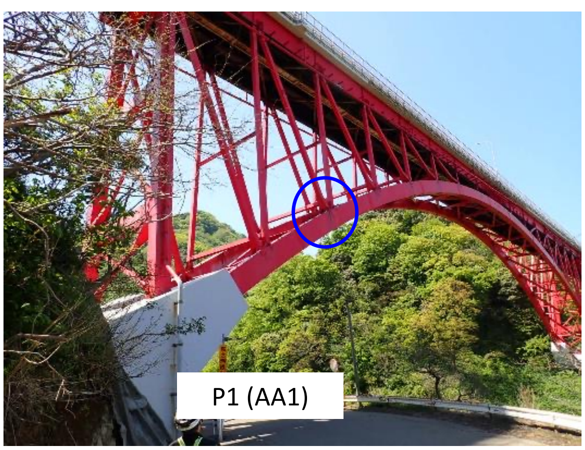

355
1200
2520
965
1
2
3
VPL21-①

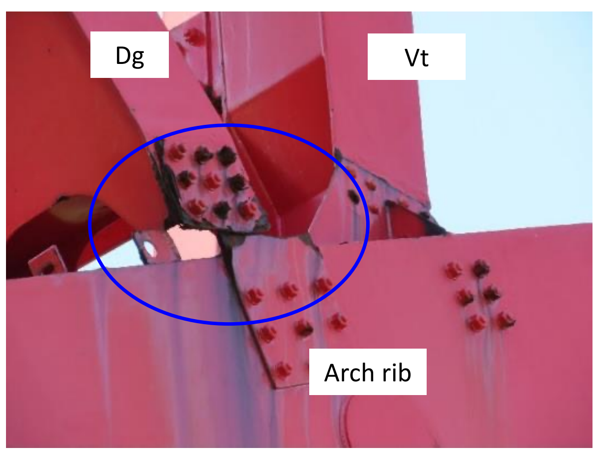

2
3
1
1500
5250

Bridge B

- ✓ Steel arch bridge
- ✓ L = 197 m, ADT = 9,600, ADTT = 2,500
- ✓ Located near the shoreline







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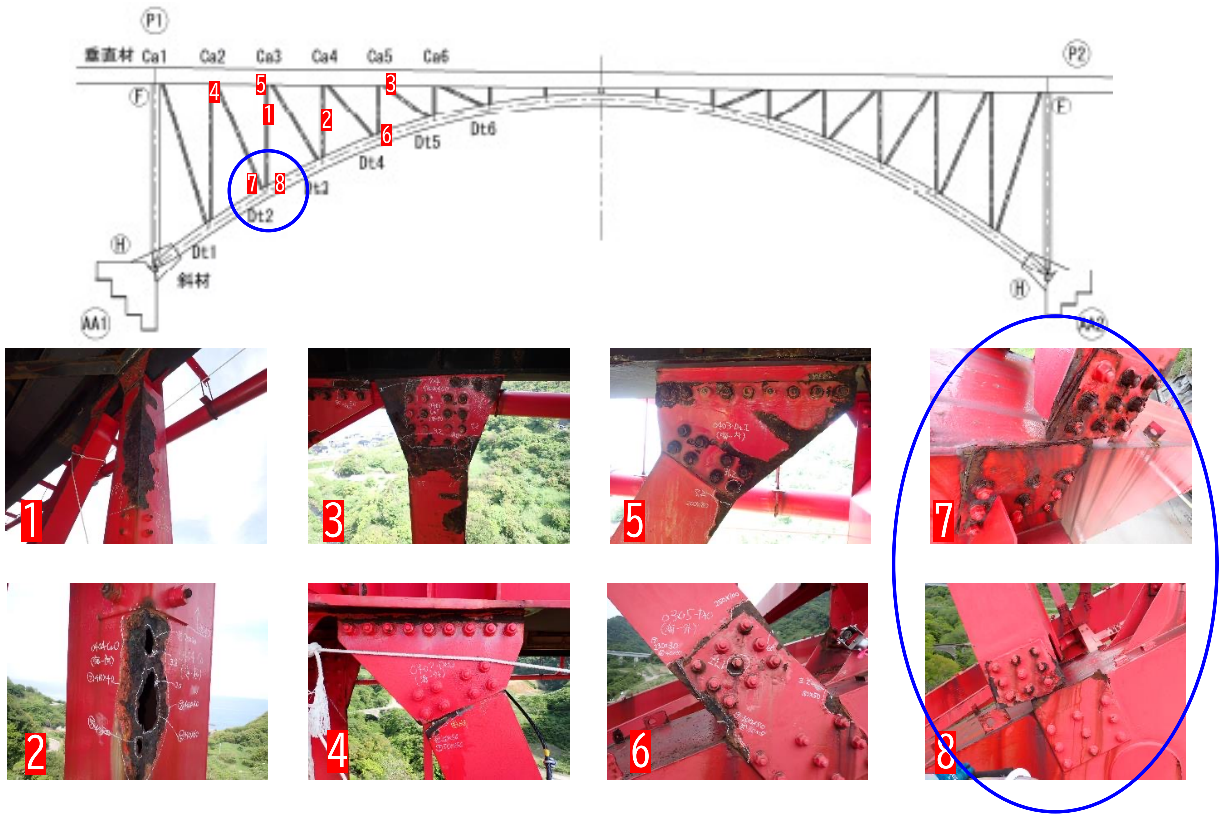
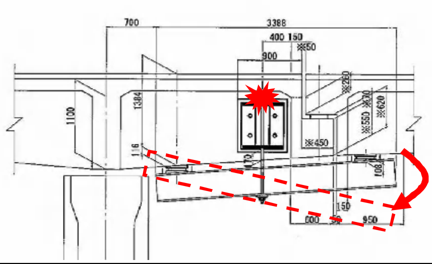

P1
垂直材 Ca1 Ca2 Ca3 Ca4 Ca5 Ca6
P2
F
Dt1 Dt2 Dt3 Dt4 Dt5 Dt6
H
斜材
AA1
1 2 3 4 5 6 7 8

10

Bridge C

- ✓ Reinforced concrete bridge
- ✓ L = 119.7 m, ADT = 12,977, ADTT = 1,904
- ✓ Backup structures to the Gerger hinges were placed.



Distress in concrete jackets


Issues

Seismic retrofit may indicate that the bridge will be used for a long time.

- What rules should be included in the design specifications or standards for refurbishment, retrofit, and repair of existing bridges to ensure durability after the work is completed?
- What minimum requirements should be included for durability design in seismic reinforcement?
  - For existing parts
  - For newly added parts


Topic 2-D 2-E
Post-Event Management
New Technology, Knowledge Update

Seismic Retrofit of Bridges and Structures

Post-Event Management
New Technology, Knowledge Update
Brief Presentations

- Post-event response/recovery technology (Nick MURRAY, Chris TRAINA)
- Seismic retrofit with damping devices (Michio OHSUMI)

Topic 2-D
Post-Event Management

Seismic Retrofit of Bridges and Structures

Post-Event Management Discussion

1. Most significant lessons and/or policy changes in emergency response and recovery after recent events
2. Maintaining an inventory of temporary bridges and repair materials, prefabricated elements, and equipment
   a. Decisions for quantity and storage locations
   b. Deployment for disasters or non-disaster-related purposes (e.g. temporarily spanning a severely deteriorated structure)

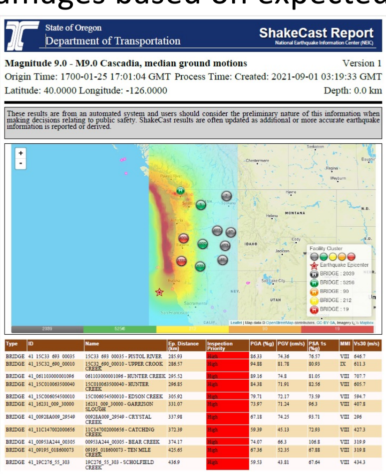
Post Extreme Event Inspection

- While primarily focused around earthquake response, the same concepts may also be applicable to other large spread extreme events (floods, tsunamis, coastal storms, etc.)

Photo by Ray Williams

Notification and Inspection Boundary

- Many states use ShakeCast or similar products to rapidly provide estimated damages based on expected levels of shaking and fragility curves.



State of Oregon
Department of Transportation
ShakeCast Report
National Earthquake Information Center (NEIC)

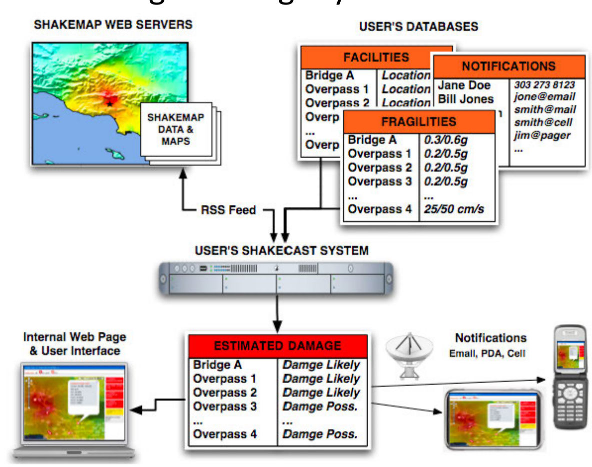
Magnitude 9.0 - M9.0 Cascadia, median ground motions Version 1

Origin Time: 1700-01-25 17:01:04 GMT Process Time: Created: 2021-09-01 03:19:33 GMT

Latitude: 40.0000 Longitude: -126.0000 Depth: 0.0 km

These results are from an automated system and users should consider the preliminary nature of this information when making decisions relating to public safety. ShakeCast results are often updated as additional or more accurate earthquake information is reported or derived.

Type	ID	Name	Ep. Distance (km)	Inspection Priority	PGA (%g)	PGV (cm/s)	PSA 1s (%g)	MMI	Vs30 (m/s)
BRIDGE	41_15C33_693_00035	15C33_693_00035 - PISTOL RIVER	285.93	High	86.33	74.36	76.57	VIII	646.7
BRIDGE	41_15C32_690_00010	15C32_690_00010 - UPPER CROOK CREEK	286.57	High	94.88	81.78	80.93	IX	611.3
BRIDGE	41_061103000001096	061103000001096 - HUNTER CREEK	295.52	High	89.16	74.8	81.05	VIII	707.7
BRIDGE	41_15C010063500040	15C010063500040 - HUNTER CREEK	296.85	High	84.38	71.91	82.56	VIII	605.7
BRIDGE	41_15C006054500010	15C006054500010 - EDSON CREEK	305.92	High	79.71	72.17	73.59	VIII	594.7
BRIDGE	41_16231_009_30000	16231_009_30000 - GARRISON SLOUGH	331.07	High	73.97	71.24	96.3	VIII	407.8
BRIDGE	41_00928A009_29549	00928A009_29549 - CRYSTAL CREEK	337.98	High	67.18	74.25	93.71	VIII	296
BRIDGE	41_11C147002000656	11C147002000656 - CATCHING CREEK	372.39	High	59.39	45.13	72.93	VIII	427.3
BRIDGE	41_00953A244_00305	00953A244_00305 - BEAR CREEK	374.17	High	74.07	66.3	106.8	VIII	319.9
BRIDGE	41_09195_018600073	09195_018600073 - TEN MILE CREEK	425.65	High	67.36	52.35	67.88	VIII	319.8
BRIDGE	41_19C276_55_303	19C276_55_303 - SCHOLFIELD CREEK	436.9	High	59.53	43.81	67.64	VIII	434.3



Inspection Boundary

- Various trigger mechanisms are followed by different agencies, often in combination with automated processes like ShakeCast
- Frequently reports of damage will begin to flow in and extents of damage will become more obvious
  - Social media or traditional media reports can be used to gather information (beware of false information)

Table 1: Post Earthquake Response Action Plan

Earthquake Magnitude	Radius of Response*
M < 4.5	N/A
4.5 – 5.0	25 miles
5.1 – 6.0	50 miles
6.1 – 7.0	75 miles
7.1 – 8.0	100 miles
M > 8.0	150 miles

**Radius of Response (measured from the earthquakes epicenter) shall be considered as a preliminary estimated distance for planning a post-earthquake response only and shall not prohibit any response outside this area if deemed necessary. This action plan is applicable when the earthquake's epicenter is located within the state of Oregon or within the radius of response from the Oregon coast or state border.*

Inspection Boundaries – Lessons Learned

What is the right area to inspect infrastructure following a large earthquake?

-Often time the maps representing strong motion change rapidly in the hours and days that follow an earthquake as more information is gathered

-How can we best deploy resources to ensure critical infrastructure is inspected timely?

Levels of Inspection

As an example:

Informal Observations
- Information from non-DOT staff: public, fire fighters, police, etc

Level 1
- Inspection by maintenance or other non-bridge personnel
  - Typically performed within 24 hours after event

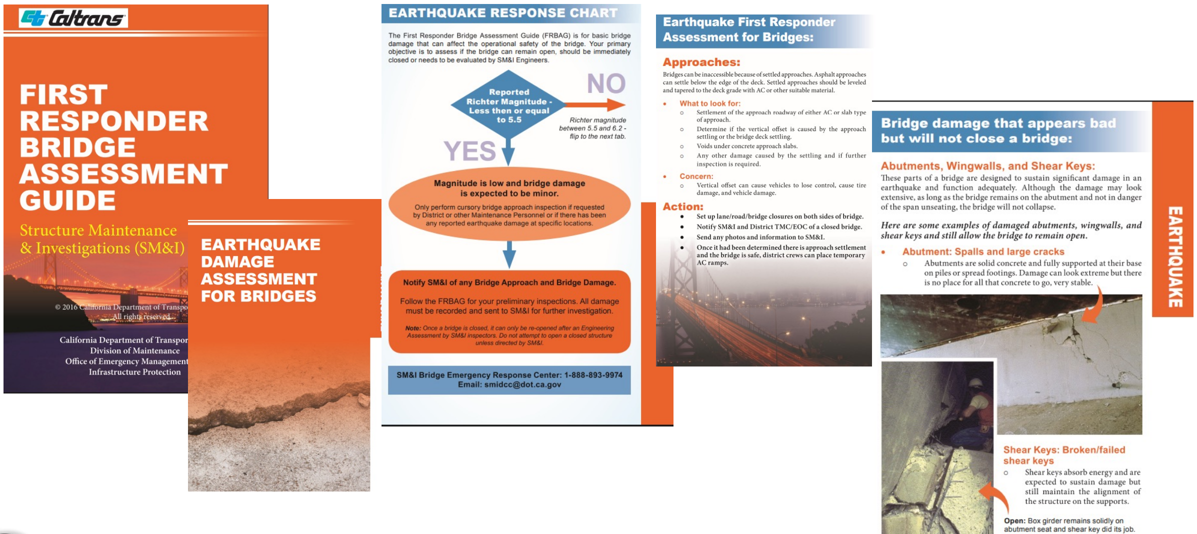
Level 2
- Inspection by qualified bridge inspectors
  - Ideally performed within 72 hours after event

Level 3
- More detailed inspection for shoring or repairs
  - Performed as needed

Levels of Inspection – Lessons Learned

- When performing level II inspections, it was determined that numerous structures had never received a level I inspection.
- No formal documentation was collected from any level I inspections.
- How can we ensure coordination between maintenance personnel that are not accustomed to inspecting structures?

Inspection Guidance



Inspection Guidance – Lessons Learned

- Non-bridge inspectors can be hesitant to make a call about leaving a bridge open or closed and may err on the side of caution
- Emerging technology like satellite internet may allow bridge inspectors to remotely help non-technical staff evaluate structures
- Alaska is currently working on a research project that allows AI to evaluate photos of reinforced concrete columns in real time and predict a damage state

Analysis Component	Computer Vision Analysis Results	Ground Truth (Actual)
Number of Horizontal Cracks	11	12
Number of Vertical Cracks	2	1
Maximum Length of Spalled Region (px)	N/A	N/A
Column Width (px)	N/A	N/A
Number of Transverse (Horizontal) Bars	N/A	N/A
Number of Longitudinal (Vertical) Bars	N/A	N/A
Damage State (DS)	1	1

Original Image: Dr. Haber

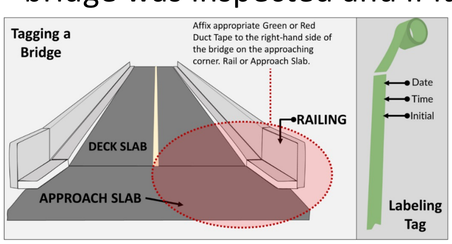
Inspection Guidance – Lessons Learned

- Unlike more common extreme events, earthquakes and tsunamis have much larger recurrence intervals.
- How can we keep inspectors/managers trained and up to date when events may only occur every 15 years?
- Between 2002 Denali Earthquake and 2018 Anchorage Earthquake only 4 staff members in Alaska DOT were employed during both events

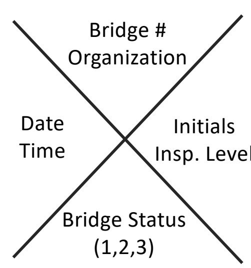
- Drills and refresher training
  - Tabletop exercises
  - Functional exercises with defined goals
  - Use smaller events as launching point for simulated response

Bridge Marking

- Physical marks left on bridges for other inspectors/officials to indicate that bridge was inspected and if it should be opened to traffic.

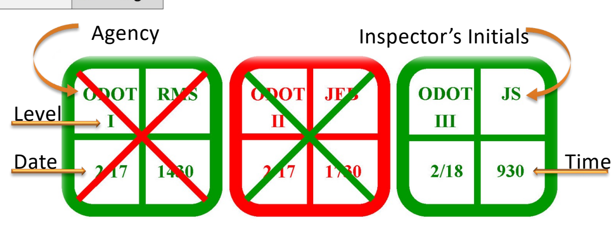


Washington State DOT



Alaska DOT&PF

Oregon State DOT



Bridge Marking Examples

Bridge Marking – Lessons Learned

- Marks or flagging on the inside of barriers or signage can become obscured or removed due to snow plowing operations or high winds
- Color based markings may prove easy to interpret but require an adequate supply of appropriate marking equipment
- Some have advocated for the use of QR codes, but without electricity or internet these may not be accessible.

Temporary Shoring/Bridges

- Temporary shoring or temporary bridges may be staged and deployed following a large earthquake

Temporary bridging installed in Chile after 2010 Maule EQ

Alaska for instance has several hundred meters of temporary bailey bridge stored in various locations around the state that can be installed quickly following an emergency

Temporary Shoring/Bridges – Lessons Learned

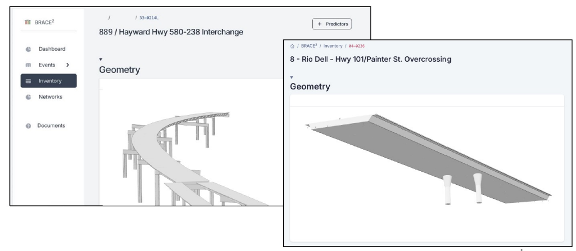
- Who has ultimate authority to dictate where temporary bridges should and shouldn't be used?
- Some of Alaska's emergency bridges have been used for other less immediate needs and remained in place for several years
- There is nothing more permanent than a temporary repair!

Temporary bridge being used on hiking trail →

BRACE2 Overview & Approach

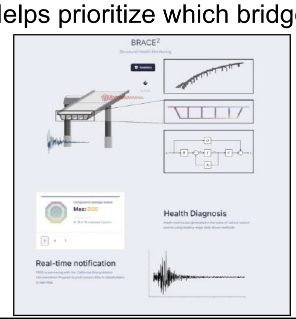
BRACE2 – Bridge Rapid Assessment Center for Extreme Events by Univ of California Berkely

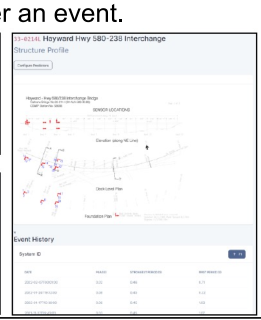
- Objective:
  Enhance seismic resilience and safety of California's bridges using smart infrastructure and advanced computational methods.
- Goals:
  Rapid post-earthquake bridge assessments
  Minimize downtime & improve disaster response
  Support Caltrans in data-informed decisions
- Core Technologies:
  Digital Twins
  Machine Learning (ML)
  Structural Health Monitoring (SHM)
  Real-time Data Streaming



BRACE2 Overview & Approach

- Key Components:
- Bridge Database: Each bridge is tracked using a digital model (digital twin).
- Prediction Tools:
-     Type I: Very detailed, based on physics and real engineering rules.
-     Type II: Faster, uses data and AI to predict behavior.
- Evaluation System: Checks damage after earthquakes using data from different tools.
- Dashboard: Helps prioritize which bridges need attention after an event.



Critical Corridor Identification

BRACE2 – Bridge Rapid Assessment Center for Extreme Events by Univ of California Berkely

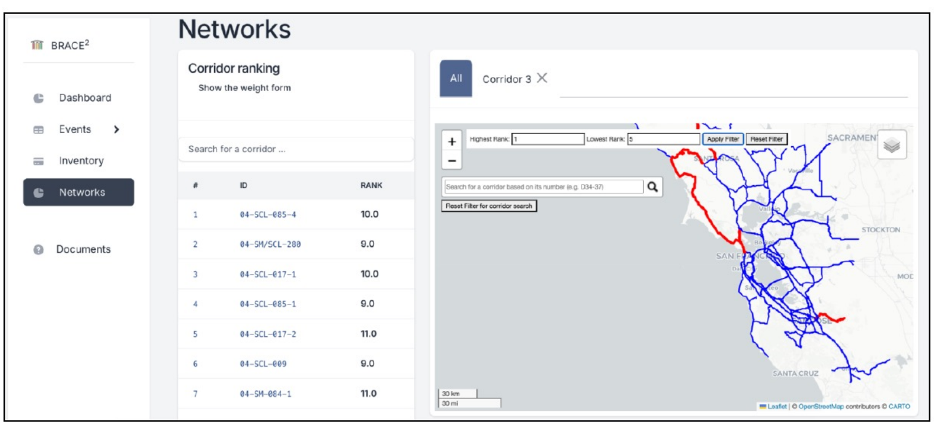
- Objective:
  Develop a tool to identify critical transportation corridors and determine whether a bridge should be designed to the Recovery Bridge performance standard.
- Recovery Bridge Definition: A bridge designed with enhanced seismic criteria to remain operational after moderate earthquakes and sustain only moderate damage during severe seismic events.
- Tool Functionality:
  - Identifies critical origin-destination pairs (e.g., hospitals, emergency services)
  - Maps shortest paths and associated corridors
  - Assesses bridges within those corridors for potential Recovery Bridge designation

Critical Corridor Identification

What's Next:

Expand the tool to more areas (like LA and Sacramento).

Help stakeholders make consistent, informed decisions.



Contingency actions in the management of bridge and structures

Immediate recovery of national highway networks in March 2011 Tohoku Earthquake

Masahiro Shirato, PhD

National Institute for Land and Infrastructure Management, MLIT, GoJ

MLIT (Ministry of Land, Infrastructure, Transport, and Tourism), GoJ

- Policy Bureau
- National and Regional Planning Bureau
- Land and Water Bureau
- City and Regional Development Bureau
- Housing Bureau
- River Bureau
- **Road Bureau**
- Road Transport Bureau
- Housing Bureau
- Railway Bureau
- Maritime Bureau
- Ports and Harbors Bureau
- Civil Aviation Bureau
- Hokkaido Bureau

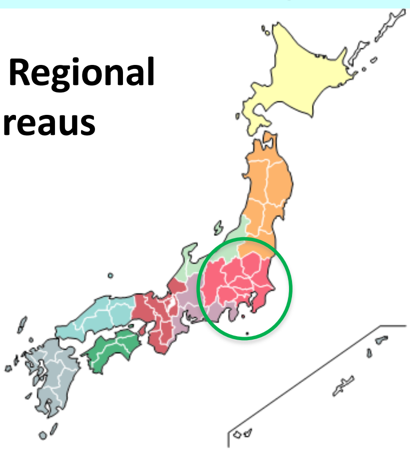
Japan Tourism Agency
Japan Transport Safety Board
Japan Meteorological Agency
Japan Coast Guard

Road network in Japan

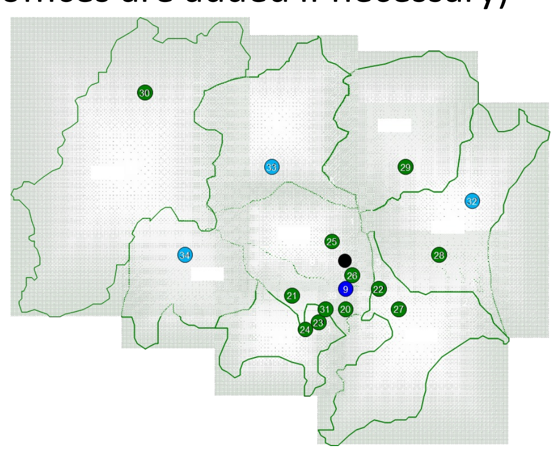
Roadway categories	Owner (Admin.)	Road length (km)	Heavy truck travels
National Expressways (Toll roads)	Government <u>(Designated corporations</u>**)**	7,400 **<u>(0.6%)</u>**	**<u>28%</u>**
National Highways ***Designated sections***	Government	22,200 **<u>(1.9%)</u>**	**<u>29%</u>**
National Highways *Non-designated sections*	Prefectures	32,000 (2.7%)	
Prefecture roads	Prefectures	128,700 (10.9%)	43%
Municipal roads	Municipalities	992,700 (83.9%)	

MLIT Institutions
for operating 22,000km NH designated sections

10 Regional Bureaus



In principle,
1 NH office in 1 Prefecture (State)
(Special purpose construction offices are added if necessary)



An NH office has

- **Planning division**
- **Construction division**
- **LA division**
- **Road property management division**
- **Road maintenance division**
- **Traffic safety division**

+ Each NH office has several blanches on site.

MLIT TEC-FORCE from other 7 Regional Bureaus followed up the initial action of Tohoku RB.

Nearly 100 TEC-Force MLIT officials from other RBs were on the ground on Day 3 for this operation and replaced continuously.

Liaisons were sent to 4 prefectures and 31 municipalities.

Another TEC-Force Unit for communication systems put up satellite communication vehicles at damaged municipalities.

MoU between the Regional Bureau and local builders regarding disaster recovery work

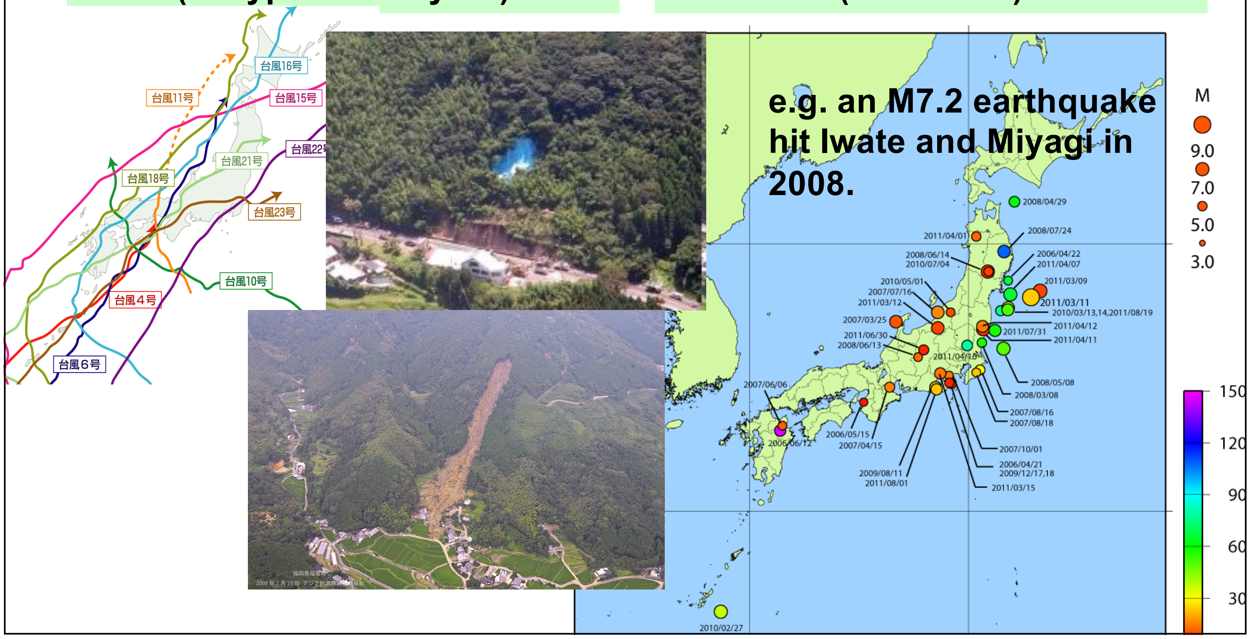
Builders with MoU automatically provide machines and operators after the disaster in no time.

The RB ordered to temporally stop all construction works procured by the RB.

MLIT deals with disaster operations on the ground.

Heavy rain (10 typhoons a year)

Large earthquakes (2006-2011)



TEC-Force (Technical Emergency Control Force)

- **MLIT HQ = Command**
- MLIT's Technical Research Institutes = Technical Specialists
- 2600 technical officials at MLIT's 11 Regional Bureaus hold double office orders of their usual office order and TEC-Force office order.
- Machines and equipment that are used at different national highway and river offices countrywide in normal time will be sheared in emergency beyond jurisdiction areas.

350 pump vehicles

250 lighting vehicles

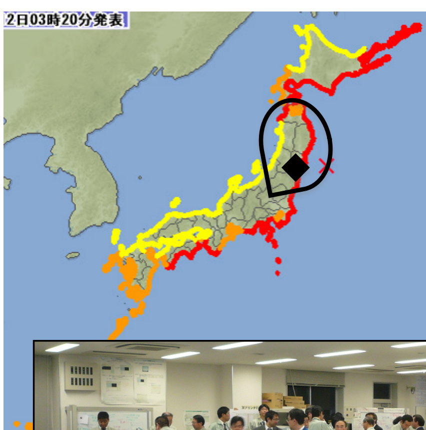
50 Satellite communication vehicles

- TEC-Force officials have to take trainings periodically.

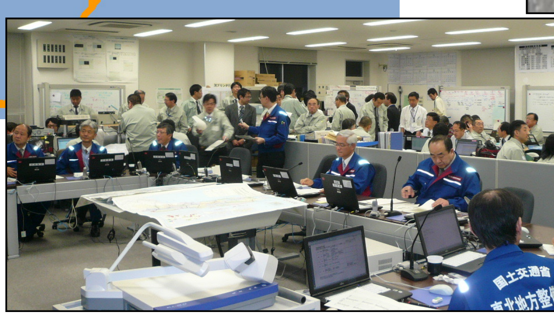
1961 Basic Act for Disaster Control Measures & Regional MOU

The emergency recovery operation for NHs owned by Prefectures was taken up by MLIT.

MLIT Tohoku Regional Bureau (≈ NHAI HQ) soon understood the situation.



MLIT NE R-B's Helicopter & Sendai Airport



The truth was… almost all communication measures and transportation were down in a vast area along the coast .

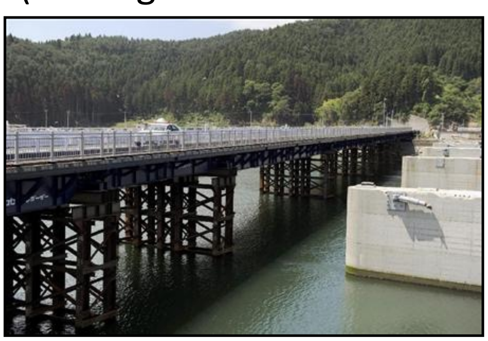
Stored temporary bridge unites were also used.

4 April 2011

Speed up the construction of the last one-mile

Use full of our technical capabilities

A temporary bridge of Kesen Ohashi Bridge was open in 10 July 2011.
(Making use of marine construction practice such as port piers)



■応急組立橋

・国では応急組立橋を51橋保有しており、うち18橋を使用中（2025.4.1時点）
・架設方法が限定的であったり、現場ヤードが必要なこと、幅の調整ができないことで、多様なニーズに対応できない場合がある

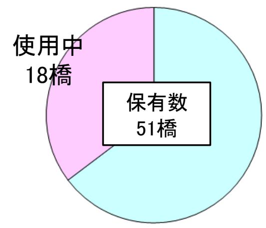
2022.8大雨による被災（大巻橋）

2023.8台風7号による被災（岡山県大石大木山橋）

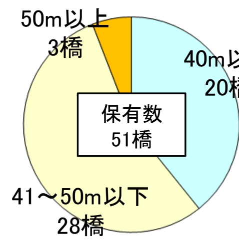
応急組立橋
（下路式ワーレントラス橋）

応急組立橋
（組立式下路ポニーワーレントラス橋）

利用状況（直轄）



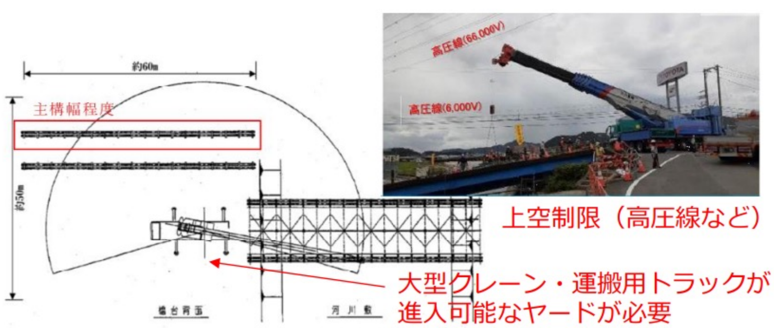
適用支間長（直轄）



■応急組立橋

・2001～2021に水害により道路橋が被災した90事例では、応急組立橋が対応できない例は少なくない。

■応急組立橋の架設方法（クレーン架設）



施工ヤード、上空・幅制限による架設不可事例

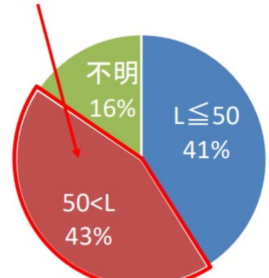
施工ヤード確保不可	36事例
上空・幅制限	3事例

（90事例のうち）

■被災した橋の支間長

ほぼ全数が適用支間50m

被災した橋の支間長の比率
約半数は適用できない



被災90事例の支間長割合

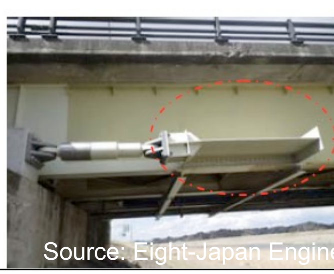
Topic 2-E, New technology, knowledge update

Seismic retrofit with damping devices

Back ground

- Current status of Damping Devices
  - No established method for designing bridges using seismic dampers.
  - But, one of the effective methods for retrofitting of existing bridges designed for L1EQ.
  - MLIT has solicited technology proposals for "seismic damper technology that contributes to improving the seismic resistance of road bridges" and has compiled and published the results as a technology comparison table.
- Unexpected damage at the attachment points in past earthquakes




Source: Eight-Japan Engineering Consultants Inc.

Example of when the damper was ineffective

・Year of Construction：1971　　　・Length：110.8m

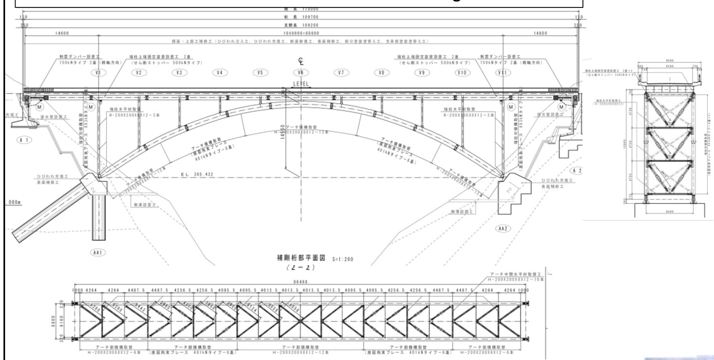


Fig-1 Side view・Ichnography・Section(Minami-Aso Bridge)

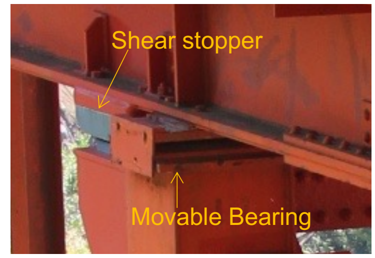


Photo-1　Traces of Scratch at Sliding Plate of Pier-end top

Photo-2　Failure of Bearing Set Bolts

Photo-3
Failure of Attachment of Damping Device

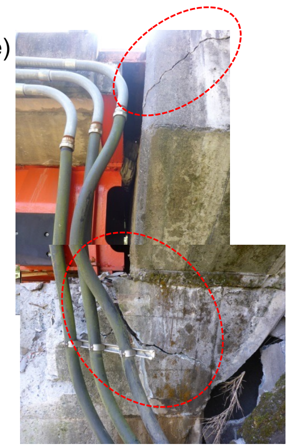


Photo-4 Failure of Abutment

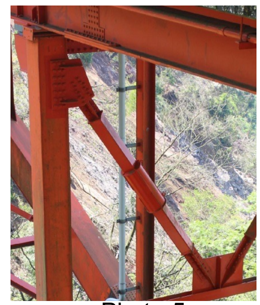
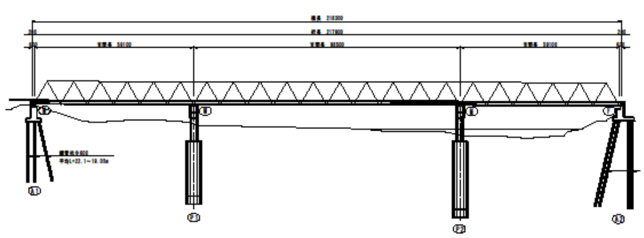
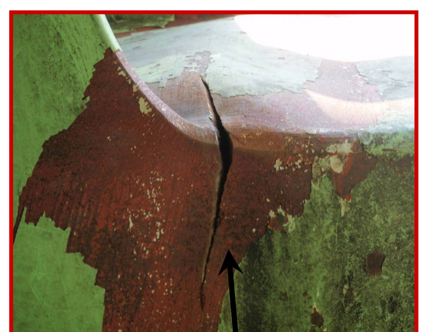


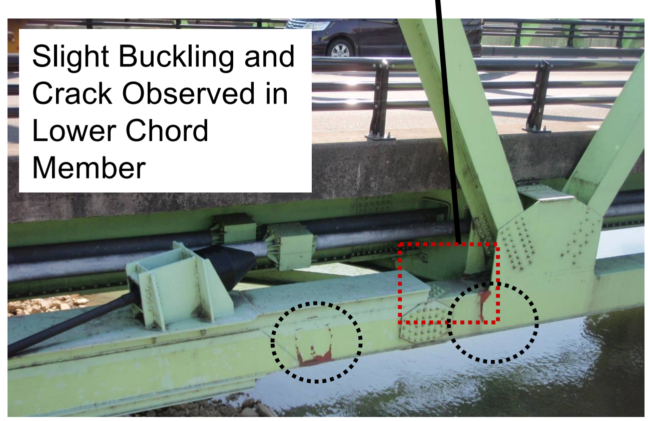
Photo-5
Buckling Restrained Brace and Other Attachments
(No deformation)

Unexpected damage caused by seismic retrofit



・Year of Construction：1972　　　・Length：218.3m





Proposals for designing bridges using dampers

Possible ways to position seismic dampers in the design of road bridges → The choice of positioning depends on the level of reliability that can be achieved through design calculations.

① Treat as load-bearing members with both resistance and damping:
Assumes dampers possess equivalent reliability to other primary load-bearing elements.

② Expecting damping only; not resistance (but check for adverse effects):
Applicable when the damper exhibits significant velocity dependence and resistance performance is uncertain. Only a minimum guaranteed level of damping is credited.

③ Expecting resistance only; not damping:
Treated like a quasi base-isolation bearing—used as a safety buffer. =Typical structural elements (though sometimes Rayleigh damping or similar is assumed implicitly).

The positioning of dampers in the draft Specifications for Highway Bridges

④ Treat as load-bearing members only in Limit State 2 verification, but not in LS 3:
Reflects the judgment that damper reliability is insufficient to rely upon for ultimate safety.

⑤ Not expect for the bridge's load-bearing performance:
Damper reliability deemed low; structural performance must be verified both with and without dampers—

The degree of reliability that can be ensured depends on various factors:

- The intrinsic reliability of the damper itself
- Preconditions for ensuring performance reliability
- Quality control measures such as inspection, process management, and maintenance
- Impacts of uncertainties on the overall bridge response, and uncertainties in response estimation
- Design provisions that account for those uncertainties

Types of Dampers(examples of classification by mechanism)

□ Hysteretic Dampers
The energy of seismic motion is consumed and damped by the energy required for deformation when the components of a damper are installed in the direction of vibration, and the components are made to yield in the direction of vibration and undergo plastic deformation.

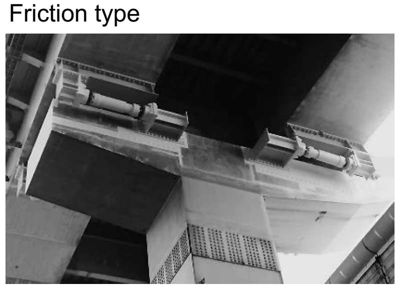
□ Friction Dampers
The energy of seismic motion is consumed and damped by frictional heat generated when two components of a damper are made to slide by friction.

□ Viscous Dampers
Viscous material filled in a sealed container flows through a wall surface and consumes and attenuates energy due to seismic motion by the resistive force generated at that time.

Hysteretic type

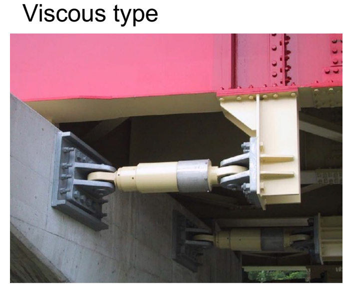
※1

Friction type



※2

Viscous type



※3

Source:
※1 Ministry of Land, Infrastructure, Transport and Tourism https://www.cgr.mlit.go.jp/ctc/pdf-document-years/2009/okayama_6-4.pdf
※2 Japan Innovation Center of Civil Engineering https://www.jice.or.jp/cms/kokudo/pdf/review/awards/kenmane/kenmane202203_02.pdf
※3 SHO-BOND Corporation https://www.sho-bond.co.jp/method/004.html

Design issues with dampers (draft)

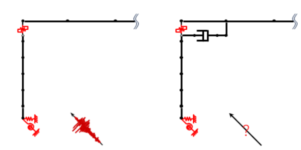
	Issues
Earthquake Motions	・Setting way of the most disadvantageous earthquake motions to the bridge with dampers ・ input direction, phase characteristics, period characteristics
Modeling for response calculation	・Applicability of 3D response to frame models ・Frame model for skewed and curved bridges（Possibility of ignoring skew angle or damper attachment angle） ・Estimating various dependencies in hysteresis model ・Coupling of bearing's and damper's hysteresis model ・Eigenvalue analysis methods and assumptions for damping ratio
Verification	・Selecting cross-sections for verification ・Estimation of partial safety factors (Estimate how much variability affects the response) ・Collision effect at damper device and its attachment
Resistance	・Setting of Load-displacement (skelton) curve ・Design of attachment member
Quality control Fabrication Construction	・Process control and testing protocols ・Material specifications and dependency in temperature, velocity, pressure, deformation, cycle, etc. ・Acceptable error range in installation for load-bearing performance
Maintenance and management	・Durability considerations ・Ease of inspection ・Ease of replacement

Earthquake Motions

□ Setting way of the most disadvantageous earthquake motions to the bridge with dampers

Standard accelerogram in the Specifications for Highway Bridges

Three standard waveforms are selected from a set of nonlinear time history analyses conducted on a single degree of freedom system.



What are the severe seismic motions for a complex vibration system when installing vibration control dampers?

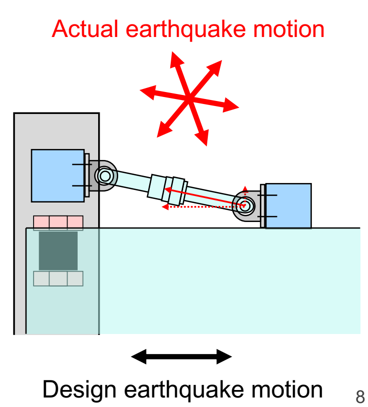
□ Input direction

Design

- Behavior considered in design: response under horizontal excitation in one direction only.
- Dampers are not modeled for excitation perpendicular to the bridge axis.

Actual phenomenon

- Actual earthquakes are 3-dimensional shaking.



Modeling for response calculation

□ Applicability of 3D response to frame models

Appropriate understanding of actual behavior (3D)

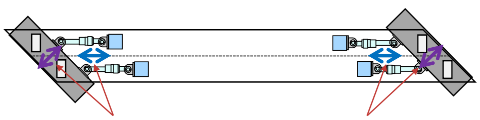
⬇ Vibration need to be applied in directions other than the damper operating axis direction in the experiment.

Application to frame models

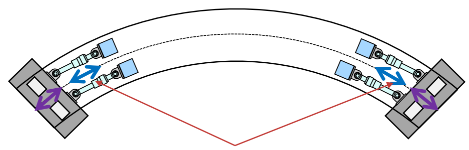
□ Frame model for skewed and curved bridges（Possibility of ignoring skew angle or damper attachment angle）

<u>Skewed bridges</u>:
Effects of the weak and strong axes of the substructure and the weak and strong axes of the damper.

<u>Curved bridges</u>:
Effects of the weak and strong axes of the damper for each substructure.



The direction in which the substructure is prone to deformation and the direction in which the damper operates are different

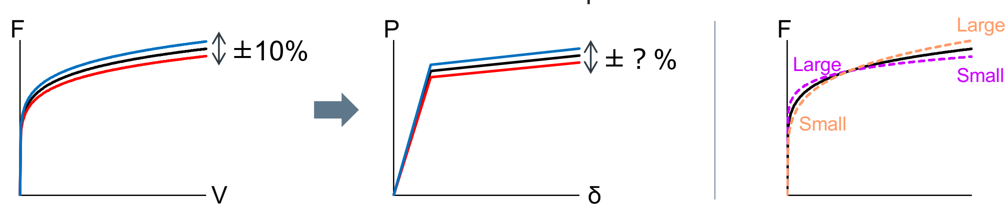


The direction of the damper actuation axis is different for each substructure

Modeling for response calculation

□ Estimating various dependencies in hysteresis models

How to take into account the variation of various dependencies

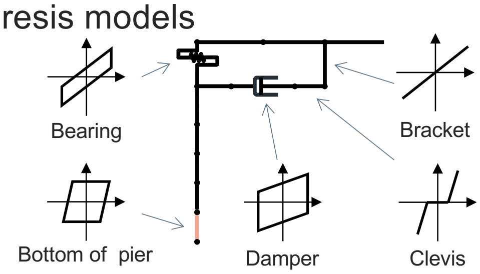


□ Coupling of bearing’s and damper’s hysteresis models

In current design practice, the bearing and the damper are defined at the same location in the analysis model.

⬇

What should be considered in the analytical model to ensure a safe design?



□ Eigenvalue analysis methods and assumptions for damping ratio

・How to perform an eigenvalue analysis when installing a damper

・How to estimate damping ratio in a dynamic analysis

Verification

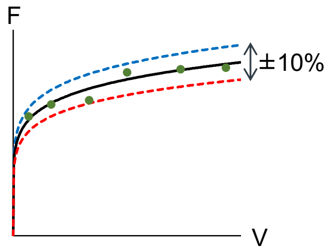
☐ Selecting cross-sections for verification

Check for excessive stresses in unanticipated locations

☐ Estimation of partial safety factors

Variability is often accounted for through partial safety factors. Seismic dampers have product variations, various dependencies, and response variations. In spite of these variations, it is important to estimate how much variability affects the response of whole bridge.

Product variations

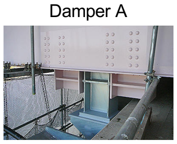


Various dependencies

Dependency factor	Hysteretic	Friction		Viscous		
	Damper A	Damper B	Damper C	Damper D	Damper E	Damper F
Velocity	No	**Yes**	**Yes[1]**	**Yes**	**Yes**	**Yes**
Temperature	**Yes**	Unconfirmed	No	No	**Yes**	**Yes**
Number of repeated amplitude cycles	**Yes**	No	–	No	No	No
Repeated amplitude magnitude	Unconfirmed	No	No	No	No	No

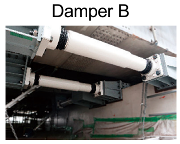
[1] Velocity: Yes (includes "Number of repeated amplitude cycles")

Damper A



TAKADAKIKO Co., Ltd.

Damper B



Asunaro Aoki Construction Co., Ltd.

Damper C

OBAYASHI CORPORATION

Damper D

OILES CORPORATION

Damper E

Yokogawa Bridge Corp.

Damper F

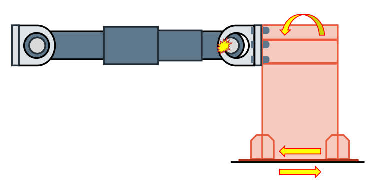
Kawakin Core -Tech Co.,Ltd.

Source:
Ministry of Land, Infrastructure, Transport and Tourism https://www.mlit.go.jp/report/press/kanbo08_hh_000828.html

Verification

☐ Collision effect at damper device and its attachment

If impact forces are applied during an earthquake, damage may occur due to impact stress in the mounting area.



➡ Are impact forces generated?, and if so, how significant effects?

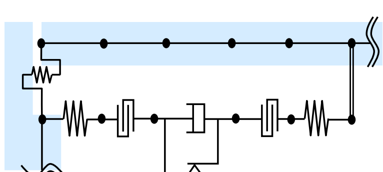
■ Analytical Study of Impact Effects

Impact generated during damper actuation was modeled and analyzed using collision springs and impulse loads.

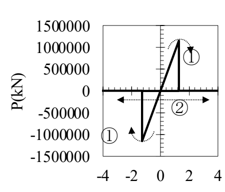
⬇

The analysis revealed that the impact force had little effect on the response.

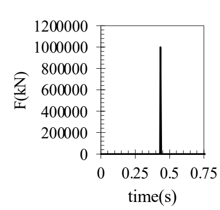
⬇



Impact spring or Impulse load



Impact spring



Impulse load

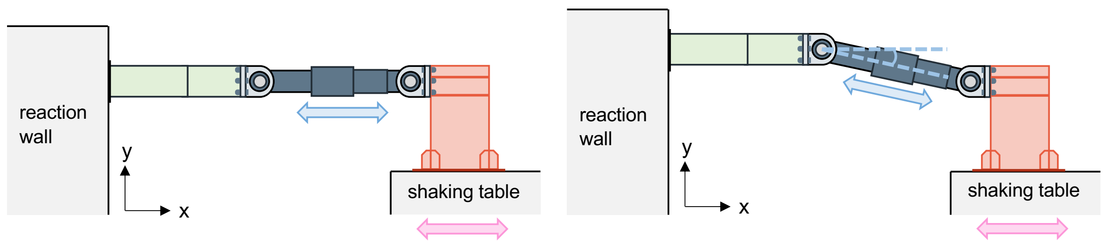
Source:
Kawamura et al.: Study on the influence of conditions of damping devices and their connections on bridge response

Resistance

□ Setting of Load-displacement (skelton) curve

Variability in the skelton curve must be accounted for by modeling conservatively.

・Effect of mounting angle (loading direction) on damping resistance



□ Design of attachment member

At the designer's discretion

・Design load of attachment member ＝ damper rated load × Safety factor

・Effect of rigidity of attachment member and Installed structure (i.e. girder web)

Quality control, Fabrication and Construction

□ Process control and testing protocols

■ Friction dampers and viscous dampers:
・Tests are conducted based on each manufacturer's internal criteria.

■ Hysteretic dampers:
・No load testing is performed before shipment.

➡ ✓ A unified quality-control framework applicable across all damper types
✓ Specific quality-control protocols defined for each damper category

□ Material specifications and dependency

・No standardized material specifications exist.
・Quality assurance based on material specifications

Dependency factor	Hysteretic	Friction		Viscous		
	Damper A	Damper B	Damper C	Damper D	Damper E	Damper F
JIS standards	✓	✓	✓	✓	✓	✓
Manufacturer's voluntary standard		✓	✓	✓	✓	✓
Other manufacturer's products	✓	✓	✓			

□ Acceptable error range in installation for load-bearing performance

・Installation of shear panel type

・Gap of installation location

Maintenance and management

☐ Durability considerations

Areas to Be Inspected Include the Following:

- Abnormalities in the main body geometry (e.g. deformation, cracks, corrosion)
- Abnormalities in mounting components (e.g. loose or fractured bolts)
- Displacement measurements
- Leakage of the filler material

☐ Ease of inspection

Consideration to enable visual confirmation of damper performance during maintenance.

☐ Ease of replacement

Consideration to allow for damper replacement.

Experiments in E-Isolation

☐ Shaking table test with full-scale seismic damper with an attachment member to confirm the resistance mechanism

■ Experimental Objectives

- Collision near expansion gap and impact factor
- Skelton curve modeling for angled attachments
- Verification test procedures
- Acceptable installation tolerances for load-bearing performance
- Design of attachment member

■ Experimental Overview

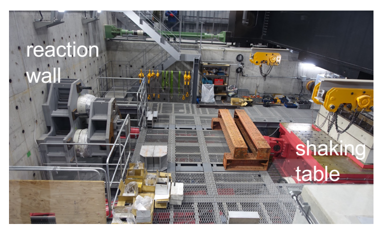
➢ Test Specimen Setup

①Installed such that the excitation direction aligns with the damper axis

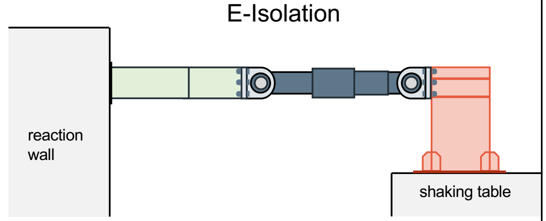
②Installed with a defined angle between the excitation direction and the damper axis

➢ Excitation Method

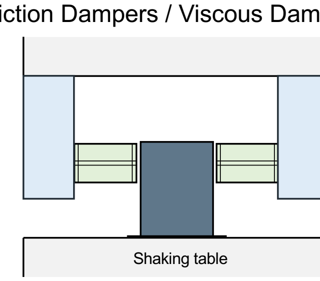
- Loading applied in the longitudinal bridge axis direction
- Verify velocity-dependent response



E-Isolation



Friction Dampers / Viscous Dampers

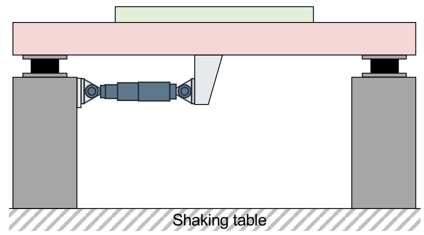


Share Panel

Experiments in E-Defense

- Response characteristics of the entire bridge system with seismic damper
  - Experimental Objectives
    - Application of 3D response to frame models
    - Frame model construction for skewed and curved bridges
    - Estimating various dependencies in hysteresis models
    - Coupling of bearing's and damper's hysteresis models
    - Eigenvalue analysis methods and assumptions for damping ratio
    - Selecting cross-sections for verification
    - Design of attachment member
    - Overall response for angled attachments

E-Defense ※

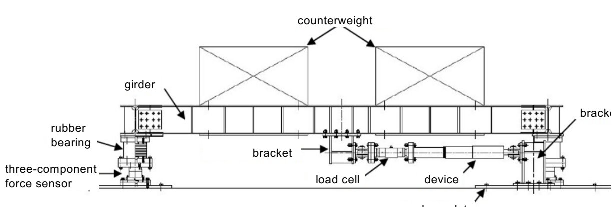


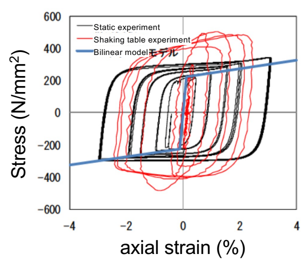
Source:
※National Research Institute for Earth Science and Disaster Resilience
https://www.bosai.go.jp/hyogo/asebi/asebi_temp/lists/download_pubfile/0802a.pdf

Studies conducted in the past

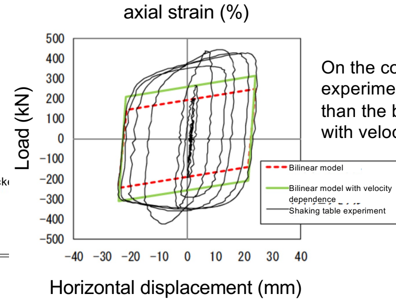
- Joint Research on Performance Verification and Design Methods for Seismic Dampers for Bridges (2009-2011)

Shaking table tests were conducted to understand the dynamic behavior of the vibration control devices.





Stresses in shaking table experiments are about 1.5 to 2 times higher than in static experiments



On the compression side, experimental results are greater than the bilinear model load with velocity dependence

Source:
PWRI et al.: Joint Research Report on Performance Verification Methods and Design Methods for Seismic Dampers for Bridges, https://thesis.pwri.go.jp/files/doken_kyoudoukenkyu_0438_00.pdf

Topic 2-E
New Technology, Knowledge Update

Seismic Retrofit of Bridges and Structures

New Technology, Knowledge Update Discussion

1. Recent retrofit technology showing promising performance and value
2. Working with new seismological knowledge (new fault, new models, …)
   Procedures and frequencies of seismic screening or re-screening
   Determining the retrofit/re-retrofit needs because of new knowledge
   a. Bridges being seismically retrofitted more than once and corresponding reasons
   b. Long-term process for the seismic screening and re-screening
   c. Frequency of re-screening, responsible agency
   d. Quantification of vulnerabilities in screening
   e. Prioritizing retrofitting decisions given the potential for increased seismic hazards

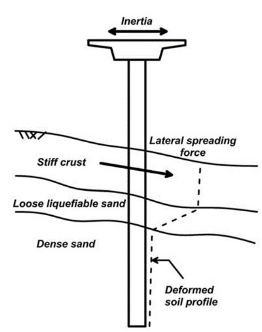
New Technology, Knowledge Update Discussion

3. Retaining structures, abutments, embankment, slopes, drainage
   a. General retaining structures, embankments, and slopes performance observations based on the most recent events
   b. Suggested design changes for slope stabilization using an anchoring system based on performance observations from the latest extreme event
   c. Evaluation of the impact of the drainage system on the performance of embankments and slopes, and are there any suggestions for drainage modification
   d. New findings based on observations from the most recent extreme events on the impact of the soil moisture condition on liquefaction potential
   e. Impact of the performance of the Geogrid Reinforced Bridge approach embankment and abutment during seismic events
   f. Performance of abutments on steep slopes during seismic events
   g. Factors impacted the bridge abutment performance, new considerations for retrofitting bridge abutments on steep slopes

Knowledge and Technology Update

- Upcoming research project: Design Guidelines for Bridge Pile Foundations Subjected to Combined Inertial and Liquefaction-Induced Lateral Spreading Loads
  - Characterize the inertial and kinematic load combination factors for highway bridges and update AASHTO LRFD guidelines with practice-oriented design recommendations

Liquefaction induced failure of abutment piles in 2023 Turkey Earthquake



Geotechnical Failures Drive Most Road Closures

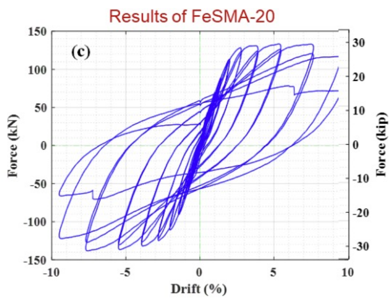
- Most roads that were closed in Anchorage following 2018 M7.1 earthquake were due to geotechnical failures.
  - While easier and quicker to repair than bridge failures, is there more we can be doing?

Geotechnical Failures Drive Most Road Closures

- What effective geotechnical retrofits can be implemented to increase seismic resilience?
- How can we convince policy makers that this work is valuable?

Knowledge and Technology Update

- Current research project: “Super-Elastic Copper-Based and Iron-Based Shape Memory Alloys and Engineered Cementitious Composites for Extreme Events Resiliency”
  - Evaluate self-centering damage-resistant columns to minimize post-earthquake permanent drift and improve post-earthquake serviceability.



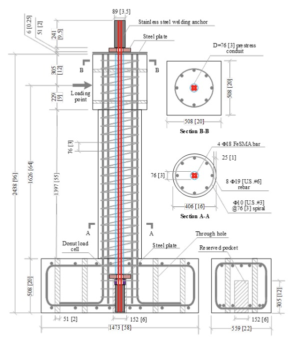


Fig. 3- Fe-SMA-reinforced column details

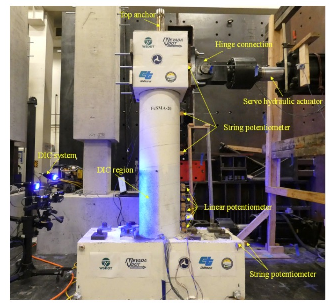
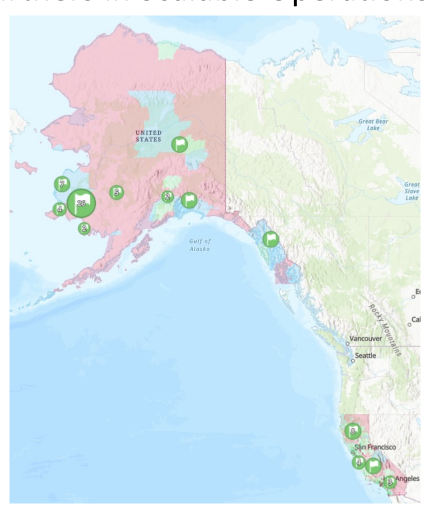


Fig. 4- FeSMA-20 test setup

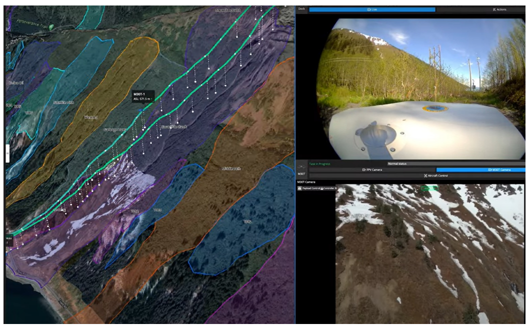
Remotely Operated UAS (Drones)

- Alaska DOT & Caltrans (along with others) are partners in Scalable Operations and Advanced Remote Technologies (SOAR)
- There are several remote drone docking platforms in California and Alaska at locations of critical but rural or hard to access locations. Allows real time drone operations from anywhere in the world



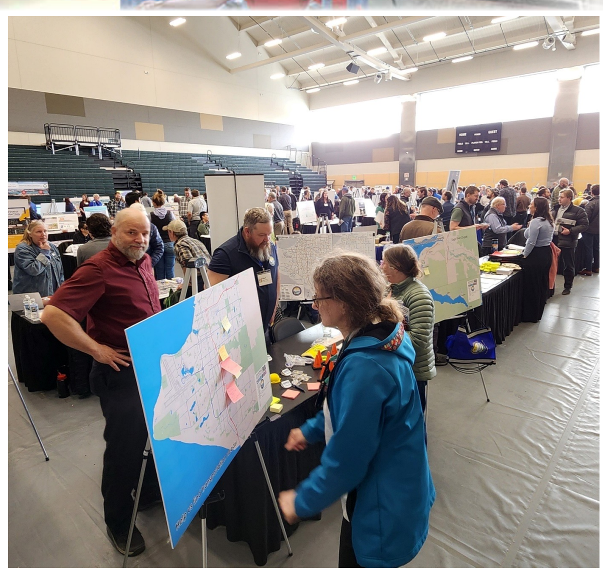
Remotely Operated UAS (Drones)

- Technology is currently being deployed to monitor and map avalanche conditions adjacent to highways. This keeps maintenance and drone operators out of potential harm. Additionally, being tested to drop explosives for avalanche control.



Setting Public Expectations

- Currently in many areas there is a false public perception that modern bridges should make it through a large earthquake without damage, when a large amount of visible damage should be anticipated but should not result in bridge collapse.
- How can we work on messaging to the public and non-engineers that this is a desired outcome that balances risk, performance and costs?
- There is generally no such thing as an ‘earthquake proof’ bridge



Setting Public Expectations

- Similarly, even if a bridge is retrofitted that does not necessarily mean that it will not be damaged during an earthquake.

Other Areas of Knowledge Growth

Use of high strength steels in seismic applications	• Currently completing shake table tests of ductile high strength reinforcing steel
Accelerated Bridge Construction details in high seismic areas	• Currently completing work for reinforcing steel couplers in plastic hinge regions
Plastic hinge relocation in columns with poor lap splices	• Finished research to relocation plastic hinges into column away from connection to footing or cap beam with short lap splices

Topic 2 - Seismic Design, Retrofit, and Management of Extreme Events

Seismic Performance of Geotechnical Elements

Seismic Post-Event Observations of the Performance of Geotechnical Elements

- Earth Retaining Structures (ERS):

    a. What are the general retaining structures, performance observations based on the most recent events?
    - Mechanical Stabilized Earth (MSE) retaining walls
    - Gravity walls
    - Anchored walls
    - Other

    b. Are there any suggested design changes to ERS systems design based on performance observations from the latest extreme event?

    c. Evaluation of the effectiveness of the ERS drainage systems in improving performance during seismic events.

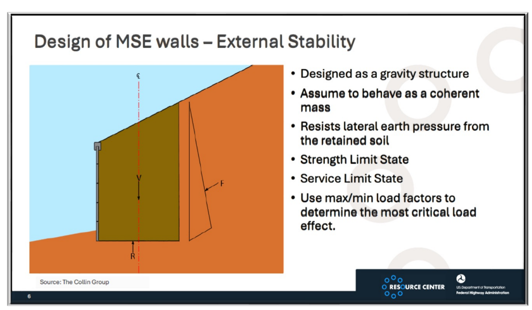


Image: FHWA

Performance of Geotechnical Elements During Seismic Events

- Natural and Manmade Slopes:
  a. What is the most observed slope mode of failure during the most recent post-event evaluation?
  b. Anchored Slopes:
     - Observations from the field evaluation of anchored slopes' performance during seismic events.
     - Are there any suggested design changes for slope stabilization using an anchoring system based on performance observations from the latest extreme event
  c. Was there an evaluation of the impact of the drainage system on the performance of slopes, and are there any suggestions for drainage modification?

Google Earth GeoEye Imagery, Oblique Views of Cliff Walls in Redcliffs
Note: Red line shows approximate pre-earthquake top of cliff. After GEER Association Inc. (2015).

Performance of Geotechnical Elements During Seismic Events

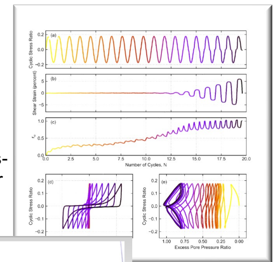
- Embankments:
  a. Evaluation of the performance of unreinforced embankments and geogrid-reinforced soil (GRS) embankments based on post-event observations
  b. Impact of the drainage system on embankment performance during seismic events (e.g. embankment failures around culverts)
  c. Type and extent of the damage to GRS embankments compared to unreinforced embankments

(FHWA: Slope and Embankment failure, AR)

Performance of Geotechnical Elements During Seismic Events

- Liquefaction:

  a. Any suggested changes for the assessment of liquefaction potential during earthquakes
  b. Are there any new findings based on observations from the most recent extreme events on the impact of the groundwater and soil moisture condition on liquefaction potential?
  c. Update to post-earthquake reconnaissance efforts to identify liquefaction at a given site based on surficial manifestations of liquefaction.



Example Response of a Liquefiable Soil During a Stress-Controlled Direct Simple Shear Test (GEC 3)

Image: FHWA

Topic 2F: Research Needs and Roadmap

- Retrofitting Methods and Programming
- Target Seismic Performance and Field Observations
- Durability and Consideration of other Design/Maintenance Factors
- Post-Event Management
- New Technology, Knowledge Update

Retrofitting Methods and Programming

- Changing criteria over time requiring retrofit or re-retrofit
- Need for a risk-based approach to retrofit decisions
- Bridge management approach for retrofitting prioritization
  - Incorporating retrofit as part of rehabilitation
  - Consideration of other strengthening needs
- Performance of retrofitted bridges may not equal a new bridge design

Target Seismic Performance and Field Observations

- Strengthening measures were successful in protecting strengthened element
- Lateral displacement limiting devices experienced damage
- Strengthening one element may shift damage to another element
- Geotechnical damage seen after recent earthquakes
  - Embankment failures
  - Slope failures

Durability and Design/Maintenance Factors

- Maintenance issues and durability of seismic retrofits
  - Affecting performance of the retrofit measures
  - Affecting performance of other aspects of the bridge
- Isolation bearing seal failures, water and debris on sliding surfaces
- Viscous damper leaks
- Restrainer cables corrosion, slackness, requiring adjustment
- Retrofit measures complicate future rehabilitation design

Durability and Design/Maintenance Factors

- Service life design for seismic retrofits: what should the design service life be? Can durability requirements be added to the design criteria for seismic retrofits?
- For reinforced concrete jacketing of columns, issues with shrinkage and temperature induced cracking. Potential for use of stainless steel reinforcing in the jacket.

Post-Event Management

- Difficulty in keeping track of which bridges have been inspected
- Methods of recording results of initial inspection after an event, on-site
- Using measured data from specific locations to predict damage from an event through real-time analysis

Post-Event Management

- Emergency response using engineering staff as first responders
- MoU with contractors to provide emergency construction/search support
- Pre-developed plans for deployment of personnel to affected areas.

New Technology, Knowledge Update

- Design processes for using damping devices has not been fully defined
- Instances of less than desirable performance in past event, related to connection of the damping devices.
- Remote operated drones may make initial survey of earthquake effects more timely.
- Setting public expectations for bridge performance in large earthquakes remains a challenge

New Technology, Knowledge Update

- Earth Retaining Structures (ERS) may require adjustments in design approach to obtain desired performance depending on type
- Slope and embankment failures have been observed.
- Drainage systems may have an impact on geotechnical failures
- Liquefaction remains a concern, can be very expensive to mitigate

New Technology, Knowledge Update

- Geotechnical information is usually very limited and dated for retrofit projects.
- Alternative forms of information may need to be utilized (geophysical testing)
- More extensive use of shear wave velocity data and direct consideration of variability of soil properties at a specific site.
- Geotechnical and Structural design criteria may not be aligned (or compatible)

Discussion on Research and Roadmaps - 1

- Seismic design needs to advance as the times have changed, in particular with relation to Nonlinear Time History Analysis.
- Element and material technology should be further developed; the seismic performance of the entire bridge should be the goal
- Pace of engineering development has decreased; it has been many years since the last major seismic events

Discussion on Research and Roadmaps - 2

- Understanding is needed regarding how the increased performance of one member will affect the other members and overall structure. Assumed versus actual behavior, and how the retrofit interacts with daily loading.
- Life cycle concepts are needed in the development of seismic retrofit designs and strategies.
- Seismic retrofit is not a topic of education in Universities, focus is on design of new bridges

Discussion on Research and Roadmaps - 3

- Both countries are working on developing or updating specifications for seismic retrofit of bridges.
- Good seismic detailing (confinement, shear capacity, ductility) has benefits for other hazards and loadings.
- Evaluation methods for the performance of restrainers, consideration of impact loads.
- Use of stainless steel as reinforcement in seismic retrofits.

Discussion on Research and Roadmaps - 4

- Resistance factors and load factors for dynamic analyses, and how these interact with the design intent regarding the load path.
- Consideration of deterioration over time, and how that effects a retrofit design. The concept of load rating for seismic hazards (through fragility functions).
- Other parts of the built environment have much to teach us, for instance on the use of dampers.

Discussion on Research and Roadmaps - 5

- Service life of retrofit elements.
- Incorporating seismic into the total asset management plan for bridges and networks, long term.
- Addressing post-earthquake damage considering aftershocks.
- Effective retrofits given the limited budget, strategies to optimize the use of available retrofit funds.

Discussion on Research and Roadmaps - 6

- For curved and complex geometries of bridges, common rules for determining axes of analysis (longitudinal and transverse for these situations.)

APPENDIX E REFERENCE GUIDES USED IN BRIDGE INSPECTION EXERCISE

Fishing Wars Memorial Bridge
Bridge Condition Rating Calibration Exercise

This exercise will evaluate the 8 concrete beam spans on the east approach to the truss. Spans are numbered from west to east. Each span has 5 girders, labeled 1 – 5, from south to north.

Scan this code to access the reporting forms

US Methodology Bridge Coding Exercise

Circle the best-fit codes below using SNBI Table 20:	
B.C.01 Deck Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.02 Superstructure Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.03 Substructure Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.12 Bridge Condition Classification	N | G | F | P
B.C.05 Bridge Railing Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.06 Bridge Railing Transitions	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.07 Bridge Bearings Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0
B.C.08 Bridge Joints Condition	N | 9 8 7 | 6 5 | 4 3 2 1 0

Report the best-fit code below using SNBI Table 15:

B.PS.01 – Load Posting Status: _________________

* - Code only based on condition of east approach structure, not the truss spans

SNBI Table 20	
Code	**Condition**
N	NOT APPLICABLE. Component does not exist.
9	EXCELLENT. Isolated inherent defects.
8	VERY GOOD. Some inherent defects.
7	GOOD. Some minor defects.
6	SATISFACTORY. Widespread minor or isolated moderate defects.
5	FAIR. Some moderate defects; strength and performance of the component are not affected.
4	POOR. Widespread moderate or isolated major defects; strength and/or performance of the component is affected.
3	SERIOUS. Major defects; strength and/or performance of the component is seriously affected. Condition typically necessitates more frequent monitoring, load restrictions, and/or corrective actions.
2	CRITICAL. Major defects; component is severely compromised. Condition typically necessitates frequent monitoring, significant load restrictions, and/or corrective actions in order to keep the bridge open.
1	IMMINENT FAILURE. Bridge is closed to traffic due to component condition. Repair or rehabilitation may return the bridge to service.
0	FAILED. Bridge is closed due to component condition, and is beyond corrective action. Replacement is required to restore service.

Table 15. Load Posting Status Codes.

	No restriction			Posted or restricted				Closed
	New	Open	Needs Action	Weight	Other	Needs Reduction	Missing	
Permanent [Bridge]	N	PO	PA	PP	PR	PD	PM	C
Temporary [Bridge]		TO	TA	TP	TR	TD	TM	C
Supported [Bridge]		SO	SA	SP	SR	SD	SM	C

Fishing Wars Memorial Bridge E
Bridge Condition Rating Calibration Exercise

Load Rating of East Approach:

NBI Rating	RF	Tons	Controlling Point
Inventory (HL-93)	0.72	25	Flexure at midspan of span 8
Operating (HL-93)	0.94	33	Flexure at midspan of span 8

Reinforced Concrete - Condition State Definitions

Defect	CS 1 - Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Delamination / Spall / Patched Area (1080)	None.	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss, but does not warrant structural review.	
Efflorescence / Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking* (1130)	Insignificant cracks or moderate width cracks that have been sealed.	Unsealed moderate width cracks or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion / Wear (1190)	No abrasion or wearing.	Abrasion or wearing has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Distortion (1900)	None.	Distortion not requiring mitigation or mitigated distortion.	Distortion that requires mitigation that has not been addressed but does not warrant structural review.	
Settlement (4000)	None.	Exists within tolerable limits or arrested with no observed structural distress.	Exceeds tolerable limits but does not warrant structural review.	
Scour (6000)	None.	Exists within tolerable limits or has been arrested with effective countermeasures.	Exceeds tolerable limits, but is less than the critical limits determined by scour evaluation and does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Fishing Wars Memorial Bridge E
Bridge Condition Rating Calibration Exercise

Japan Methodology Bridge Coding Exercise

Report the best-fit code below using Table 5.1:

Integrity Diagnosis Classification: ________________

Table 5.1 Integrity diagnosis classification

Classification		Definition
I	Sound	There are no disruptions to the functionality of the bridge.
II	Preventive maintenance stage	There are no disruptions to the bridge functionality, but it is desirable to take measures from a preventive maintenance perspective.
III	Remedial action stage	There is a possibility that the bridge functionality is being impaired and measures should be taken early.
IV	Emergency action stage	The bridge functionality is already significantly impaired, or is likely to be substantially impaired, and urgent measures must be taken.

The basic relationship between the integrity diagnosis classifications and anticipated remedial / countermeasure actions is as follows.

I: Routine and scheduled maintenance are implemented, but no further preventive measures or monitoring are required until the next periodic inspection.
II: It is timely to implement preventive and preservation measures, mainly to ensure longevity and durability, and actions are desirable before the next periodic inspection.
III: Measures need to be taken before the next periodic inspection to ensure the bridge's structural safety and prevent harm to third parties.
IV: Measures must be taken urgently to ensure the bridge safety and prevent harm to bridge users and third parties.

	Damage			Condition State (US) (1-4)
Member	**Cracking (a – e)**	**Pattern (1 – 24)**	**Exposed Rebar (a - e)**	
Span 5, Girders 1, Seg 4				
Span 5, Girders 1, Seg 5				
Span 5, Girders 3, Seg 2				

Fishing Wars Memorial Bridge E
Bridge Condition Rating Calibration Exercise

(6) Cracking, water seepage, and efflorescence

1) Classifications of damage extents

Guideline			Extent of damage
Existence of cracks	Crack width	Water leakage and free lime	
No	None or hair cracks	No water seepage or efflorescence	a
Yes	Less than 0.2 mm	No water seepage or efflorescence	b
	0.2 mm or larger	No water seepage or efflorescence	c
	Any width	Water seepage through a crack; no rust stain or efflorescence visible	d
		Efflorescence; no rust stain visible	d
		Water seepage involving notable mud-like stain or rust stain	e

2) Crack patterns

Crack patterns shall be categorized according to the tables below, and corresponding pattern numbers shall be recorded.

a) Superstructure (Common definitions for both PC and RC members)

Location	Crack pattern
Span center	(1) Transverse cracks on the bottom surface or vertical crack on the side surface/web of the main girder
	(2) Longitudinal cracks on the bottom surface of the main girder
1/4 point of span	(3) Transverse cracks on the bottom surface or vertical crack on the side surface/web of the main girder
Support section	(4) Diagonal cracks in the web at support
	(5) Transverse cracks on the bottom surface or vertical crack on the side surface/web of the girder at support
	(6) Diagonal cracks on the side of the girder at support
	(7) Cracks in in-span or Gerber hinge section or dapped-end beam
	(8) Vertical cracks in the upper part of continuous spans at intermediate support
Others	(9) Map cracking
	(10) Cracks occurring vertically at regular intervals in the web of the girder
	(11) Horizontal cracks near the junction between the web and the upper flange
	(12) Cracks in 45-extent diagonal direction occurring all over the girder
1/4 point of span, or the support section	(21) Longitudinal cracks on the bottom or side surface of the girder (excluding those that fall under (19))
	(22) Cracks on the upper flange
Entire span	(23) Horizontal cracks developed throughout the web
Cross beams	(24) Cracks on the cross beam

(7) Exposed rebars

1) Classifications of damage extents

Guideline			Extent of damage
Existence of exposed rebars	Spread of exposure and corrosion	Extent of corrosion	
No	—	—	a
Yes	Limited	Unmeasurable section loss	a
		Measurable section loss, or significant corrosion volume expansion of reinforcement	a
	Wide area	Unmeasurable section loss	a
		Measurable section loss, or significant corrosion volume expansion of reinforcement	e

[Examples]

Damage extent a

Partial rebar exposure

Damage extent a

Superficial rebar exposure over a wide area

Damage extent e

Reinforcement corrosion over a wide area

Damage extent e

Reinforcement corrosion over a wide area