United States–Japan Bridge Engineering Workshop: Innovative Bridge Design and Preservation

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Research, Development, and Technology
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FOREWORD

The United States–Japan Bridge Engineering Workshop brought together bridge engineers from the United States and Japan to exchange ideas and technologies and share critical knowledge and lessons learned. The workshop focused on innovative bridge design and preservation issues of growing interest to both countries. The following four noteworthy needs were identified:

1. Tie durability design with requirements for inspection and maintainability.
2. Develop guidelines and standards for structural health monitoring.
3. Improve accuracy of approximate methods of analysis.
4. Work on performance-based design specifications.

This report summarizes the discussion items from the workshop and will be of interest to bridge engineers.

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The Japanese topic leads were Masahiro Shirato, Jun-ichi Hoshikuma, Yoshinobu Oshima, and Michio Ohsumi. The Federal Highway Administration Contracting Officer's Representative was Sheila Rimal Duwadi.

16. Abstract
The United States–Japan Bridge Engineering Workshop brings together bridge engineers from the United States and Japan to exchange promising ideas and technologies and share critical knowledge and lessons learned to further bridge engineering. The 2018 workshop focused on innovative bridge design and preservation issues of growing interest to both countries. This report is a summary of the 2018 workshop, including discussion topics of interest 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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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 (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
Caltrans	California Department of Transportation
CFRP	carbon-fiber-reinforced polymer
DOT	department of transportation
FHWA	Federal Highway Administration
FRP	fiberglass-reinforced plastic
GFRP	glass-fiber-reinforced polymer
LRFD	Load and Resistance Factor Design
LTBP	Long-Term Bridge Performance
NBIS	National Bridge Inspection Standards
NDE	nondestructive evaluation
NILIM	National Institute of Land, Infrastructure, and Management of Japan
PC	prestressed concrete
SHM	structural health monitoring
SMA	shape memory alloy
UHPC	ultra-high performance concrete

INTRODUCTION

The United States and Japan have shared bridge engineering knowledge since 1984 when the first joint bridge engineering workshop was held. This year's workshop was part of the Bridge Engineering Collaboration between the National Institute of Land, Infrastructure, and Management of Japan and the Federal Highway Administration and conducted in cooperation with the United States/Japan Cooperative Program in Natural Resources, Task Committee G, Transportation Systems. The workshop was planned and executed in cooperation with the California Department of Transportation and Japan's Public Works Research Institute, with additional support in planning and execution provided by the Oregon Department of Transportation (DOT) and the Washington State DOT.

The workshop took place in Los Angeles, CA, from July 17 to 18, 2018 and was structured around the following four topics:

1. Bridge design, rehabilitation, and retrofitting for enhanced durability and preservation.
2. Bridge instrumentation and health monitoring.
3. Guidelines and use of refined numerical calculations for design and bridge assessment.
4. Innovative materials for bridge design and construction.

The workshop also included a one-day study tour of the 6th Street Viaduct replacement in downtown Los Angeles, CA and Gerald Desmond bridge construction in Long Beach, CA. As shown in figure 1, 43 participants (31 from the United States and 12 from Japan) discussed these topics in detail. Each participant was assigned a primary topic based on his or her area of expertise to help lead discussions and field questions.

Source: FHWA.

Figure 1. Photograph. Workshop participants.

The introductory session, Decisionmaking, Institutional Layout, and use of Specifications and Guidelines, laid the groundwork for the four topics. A barrier in collaboration between any countries in technical exchanges can be the limit in understanding the governance of transportation, research, policy, guidance, and practices in each respective country. Without a working knowledge of how each country's transportation governance functions and how decisions are made, it is difficult to understand the challenges and opportunities each country faces in developing, building, and maintaining transportation systems that meet the needs of their populations. Participants from both the United States and Japan described the process for decisionmaking, the framework for making those decisions, and how specifications and guidelines are used.

WORKSHOP SCHEDULE

The agenda for the first day of the workshop was as follows:

- 8:30 to 9:00—opening session:
  - Welcoming remarks by Sheila Rimal Duwadi of the Federal Highway Administration (FHWA).
  - Welcoming remarks by Masahiro Shirato of the National Institute of Land, Infrastructure, and Management of Japan (NILIM).
  - Welcoming remarks by Sue Hida of the California Department of Transportation (Caltrans).
  - Self-introductions.
  - Review of meeting agenda and expectations with David Sanders of the University of Nevada at Reno.
- 9:00 to 10:30—introductory session: Decisionmaking, Institutional Layout, and Use of Specifications and Guidelines.
- 10:30 to 10:50—morning break
- 10:50 to 12:00—topic 1: Bridge Design, Rehabilitation, and Retrofitting for Enhanced Durability and Preservation Part 1.
- 12:00 to 13:00—lunch.
- 13:00 to 14:15—topic 1: Bridge Design, Rehabilitation, and Retrofitting for Enhanced Durability and Preservation Part 2.
- 14:15 to 14:35—afternoon break.
- 14:35 to 17:00—topic 2: Bridge Instrumentation and Health Monitoring.

The agenda for the second day of the workshop was as follows:

- 8:30 to 10:15—topic 3: Guidelines and Use of Refined Numerical Calculations for Design and Bridge Assessment Part 1.
- 10:15 to 10:35—morning break.
- 10:35 to 11:45—topic 3: Guidelines and Use of Refined Numerical Calculations for Design and Bridge Assessment Part 2.
- 11:45 to 12:45—lunch.
- 12:45 to 14:00—topic 4: Innovative Materials for Bridge Design and Construction Part 1.
- 14:00 to 14:20—afternoon break.

- 14:20 to 15:30—topic 4: Innovative Materials for Bridge Design and Construction Part 2.
- 15:30 to 16:30—closing session and final discussion.

TOPIC 1: BRIDGE DESIGN, REHABILITATION, AND RETROFITTING FOR ENHANCED DURABILITY AND PRESERVATION

The primary participants for topic 1 are listed in table 1.

Table 1. Primary participants for topic 1.

Last Name	First Name	Affiliation
Johnson	Bruce	Oregon DOT*
Abu-Hawash	Ahmad	Iowa DOT
Goto	Jun	Metal Fatigue Solutions, Inc.
Murphy	Tom	Modjeski and Masters
Shirato	Masahiro	NILIM**
Miki	Tomohiro	Kobe University
Nakamura	Eisuke	PWRI
Nozaka	Katsuyoshi	Ritsumeikan University
Ohsumi	Michio	PWRI
Sawada	Mamoru	PWRI
Tamakoshi	Takashi	PWRI

*United States lead.
**Japan lead.
DOT = department of transportation; PWRI = Public Works Research Institute.

Advancements in building materials and detailing of bridges allow for greater service life expectations. Advancements in prediction technologies of bridge element performance in response to various deterioration drivers have led to development of rational methods to predict the service life. Despite these advances, comprehensive guidance on how to take full advantage of these trends has yet to be developed.

The discussion for topic 1 began with an overview of each country's current utilization and code requirements for advanced durability analysis and the use of highly durable materials. Participants discussed developing comprehensive service-life analysis methods and using more durable building materials in bridges. Recent advances in *Service Life Design for Bridges* for major, signature bridges was presented as a basis to further discuss more routine use of the method for regular bridges.(1)

Participants discussed current limitations and hurdles to implementing analysis of enhanced service-life methods. Knowledge gaps present in one or both countries were identified. Topics of mutual interest for continued discussion and potential future collaboration were explored.

Prior to the workshop, participants generated a broad list of topics for consideration. Following preliminary discussions, the list was reduced to three topics: service life and durability design specifications, challenges for further specification development, and specific methods of life extension and durability of bridge decks and other bridge elements.

UNITED STATES

Of particular interest to participants from the United States were the types of analysis methodologies used for designing bridge elements for a specific service life: full probability, partial factor, or deemed to satisfy. Full service life design has been accomplished for a few major, signature bridges, but the United States is just now developing specifications for routine service life design for normal bridges.

Participants from the United States were also interested in practical methods for extending service life using advanced, highly durable materials (e.g., stainless steel, ultra-high performance concrete (UHPC)) and written guidelines for evaluating the benefits of using highly durable materials over the lifecycle of a bridge.

JAPAN

Of particular interest to participants from Japan were the durability, maintenance, and serviceability requirements of the American Association of State Highway and Transportation Officials (AASHTO) *Load and Resistance Factor Design (LRFD) Bridge Design Specifications*.(2) Several journal articles describing the use of highly durable materials (e.g., stainless steel and galvanized steel girders) to satisfy design requirements were discussed.

Participants from Japan were also interested in discussing the direction of service life design and proposed enhancements to current methods to satisfy the bridge performance requirements in design codes.

Topic 1 Session Structure

The topic 1 session included presentations from primary participants followed by open discussions. Primary participants gave short presentations on their respective country's existing guidelines and practices, challenges for further specification development, and ending with topics for future research. Discussion followed each of these presentation topics.

Part 1: Recent Developments of Durability/Service Life Design Specifications/Guidelines and Implementation

Part 1 of the topic 1 session was dedicated to sharing with all participants the durability and design specifications/guidelines in the United States and Japan.

Presentations included the following:

- *Guide Specifications for Service Life Design,*(3) Tom Murphy, Modjeski and Maters.
- *fib Bulletin No. 34 and Applications in the United States,*(4) Bruce Johnson, Oregon Department of Transportation (DOT).
- *Durability Performance Requirements and Design in the Japanese Specifications for Highway Bridges,*(5) Mashiro Shirato, NILIM, MLIT.

Each presentation included the following elements:

- Background and objectives.
- Requirements, including durability, inspectability, and maintainability, and the framework and methodology to achieve the requirements.
- Reliability measurements of the service life design and overall bridge durability, inspectability, and maintainability design.
- Technical challenges of developing and implementing specifications/guidelines into practice.

There was an open discussion at the end of part 1 of this session.

Part 2: Challenges for Further Code Development of Durability or Service Life Design in Terms of Reliability and Risk-Based Inspection

Part 2 of the topic 1 session was dedicated to discussing approaches to more reasonable durability-based design that take sustainability into account. Discussions were also encouraged on harmonizing bridge design standards and inspection standards (i.e., the relationship between the reliability levels of durability design and bridge inspection frequencies).

Summary presentation 1 included background information, objectives, expected impacts on bridge inspection and preservation practices, and ongoing research on probabilistic or partial factor durability design in the United States by Bruce Johnson.

There was an open discussion at the end of summary presentation 1.

Summary presentation 2 included frequency of bridge inspections, detail of inspections, ability to skip inspections, element-based inspections, service life design, and ongoing research on these topics by Masahiro Shirato.

There was an open discussion at the end of part 2 of this session.

Part 3: Needs for Research on Specific Design and Preservation Techniques to Achieve Longer Service Life

Part 3 of the topic 1 session was dedicated to summary presentations on research needs and the prioritization of design and preservation techniques in the United States and Japan. Participants elaborated on research strategies and potential challenges and pitfalls, discussing causes and remedies for early-age cracking and deterioration of concrete.

Presentations included the following:

- United States presenter—Ahmad Abu-Hawash.
- Japan presenter—Eisuke Nakamura.

Topics of discussion from the priority lists compiled by both countries prior to the workshop included the following:

- Treatments for bridge deck deterioration.
- Early cracking.
- Connections of precast concrete members, including deck panels.
- Test protocols and certification systems to ensure the strength, durability, and terms of use regarding fatigue, corrosion, and other deteriorations in deck systems, bearings, carbon-fiber-reinforced polymers (CFRPs), and adhesives.

There was an open discussion at the end of part 3 of this session.

TOPIC 2: BRIDGE INSTRUMENTATION AND HEALTH MONITORING

The primary participants for topic 2 are listed in table 2.

Table 2. Primary participants for topic 2.

Last Name	First Name	Affiliation
Azari	Hoda	FHWA*
Alampalli	Sreenivas	New York State DOT
Chen	Genda	Missouri University of Science and Technology
Miceli	Marybeth	Miceli Infrastructure Consulting
Moon	Frank	Rutgers University
Oshima	Yoshinobu	PWRI**
Hoshikuma	Jun-ichi	NILIM
Sawada	Mamoru	PWRI
Miyashita	Takeshi	Nagaoka University of Technology

*United States lead.
**Japan lead.
PWRI = Public Works Research Institute.

The current practice for bridge condition monitoring and assessment is scheduled visual inspections. All data collected during inspections represent a snapshot of the condition of a bridge at the time of inspection. These snapshots are highly dependent on the experience of an inspector and accessibility of bridge elements. Embedded defects and hidden damages may not be captured during visual inspection, which can lead to accelerated bridge deterioration and result in more expensive repairs compared to cases where degradation was identified and mitigated earlier. Nondestructive evaluation (NDE) technologies and structural health monitoring (SHM) systems are complementary tools to assist inspectors in assessing the condition of their bridges.

NDE technologies can provide measures of bridge condition especially if there are subsurface defects both in concrete or steel bridge components. SHM systems can provide global bridge measures, such as displacement and rotation, to assist in load rating and damage detection. With heightened construction controls and the complexity of construction increasing, monitoring to ensure safety during construction and provide a baseline for performance evaluation has become more critical.

Although NDE technologies and SHM systems can provide data to augment traditional inspection approaches, there is no clear definition of the health of a structure or a structure being in a healthy state. There is no consensus of a threshold for decisionmaking in bridge management (i.e., the state corresponding to a specific maintenance or repair action). The concept of technology leveraging (i.e., real-world use of NDE technologies and SHM systems) has yet to be sufficiently developed, which is attributed to an undefined role for monitoring technologies in bridge engineering and the lack of a compelling roadmap for how emerging NDE technologies and SHM systems can be integrated into the bridge-condition assessment and performance-monitoring processes.

To define structural health, the performance of a structure should be clarified and specified in terms of functional sufficiency. Acceptable functional sufficiency criteria can be defined based on the expected remaining service life, or they can be defined based on design assumptions utilized. Japanese bridge design specifications have been revised to be performance based so that the criteria for bridge condition (i.e., condition level) can be identical for both bridge design and management. Specific threshold values can then be set to define a healthy state. Performance-based bridge design and management allow for the following:

- Establishing clearly defined performance requirements.
- Identifying specific performance measures associated with design criteria (e.g., bearing capacity, safety factor, design situation) that satisfy performance requirements with a certain reliability.

Obtaining a baseline for performance evaluation by monitoring a structure during construction allows for the possibility of evaluating the gap between design assumptions and actual performance. This evaluation is important for indicating when performance requirements are not met, and for scheduling repair, retrofitting, and rehabilitation efforts.

Prior to the workshop, participants from the United States and Japan generated a broad list of topics for consideration. Following preliminary discussions, the list was reduced to the relationship between NDE technologies and SHM systems, bridge performance, and bridge management.

UNITED STATES

Of particular interest to participants from the United States was the Japanese bridge-management system and the performance measures used by the Japanese Road Authority. Participants from the United States were also interested in learning about advanced technologies incorporated into the Japanese bridge-management system (e.g., NDE technologies and SHM systems, remote sensing, unmanned aerial systems, artificial intelligence, virtual reality). Participants from the United States were curious if Japan had any standards or technical guidelines for using NDE technologies and SHM systems and if there was a certification process.

JAPAN

Of particular interest to participants from Japan was how the healthy state of a bridge is defined in the United States and the practicality of implementing NDE technologies and SHM systems into the bridge-condition assessment and performance-monitoring process. Participants from Japan were also interested in the relationship between performance measures used in monitoring and the performance requirements or required load bearing capabilities in design specifications. Participants from Japan were curious about how reliable NDE technologies and SHM systems should be before implementing them into their bridge-condition assessment and performance-monitoring processes and how to gauge their reliability to ensure practicality after implementation.

Based on the aforementioned interests, participants from Japan wanted to discuss practical issues when NDE technologies and SHM systems were implemented in bridge-management systems and the limitation of such technologies and systems. Participants from Japan wanted to clarify how to evaluate bridge performance using NDE technologies and SHM systems and how to integrate several types of results for diagnosis. They also wanted to discuss the development and direction of monitoring technology and its practicality for use.

Topic 2 Session Structure

The topic 2 session included presentations from primary participants followed by open discussions. Primary participants gave short presentations on their respective country's current bridge monitoring and maintenance practices and their relation to bridge management. The presentations were followed by discussions on challenges for implementing NDE technologies and SHM systems and topics for future research.

Discussions focused on the necessary steps to define performance, use of performance measures to validate performance-based bridge design and management approaches, the relationship between design performance and actual performance, and how to fill gaps between design assumptions and actual performance based on data collected from NDE technologies and SHM systems. Successful case studies that used performance monitoring to confirm the effectiveness of retrofitting and to obtain baseline data for future maintenance, as well as those that used continuous monitoring to track the propagation of identified damage, were presented and discussed.

Part 1: Bridge Management and NDE/SHM Technology Leveraging

Part 1 of the topic 2 session began with a comparison of bridge assessment and management in the United States and Japan using NDE technologies and SHM systems.

Summary presentations on bridge assessment and management included the following:

- United States presenter—Hoda Azari.
- Japan presenter—Yoshinobu Oshima.

Open discussion topics included the following:

- How NDE technologies and SHM systems are implemented for bridge management, including any technical guidelines and certification processes in place.
- How advanced technologies (e.g., NDE technologies and SHM systems, remote sensing, unmanned aerial systems, artificial intelligence, virtual reality) are incorporated in the bridge-assessment and management processes (e.g., NDE/SHM, remote sensing, unmanned aerial systems, artificial intelligence, virtual reality).
- How NDE technologies and SHM systems complement or replace certain components of visual inspection.

Part 2: Successful Case Studies

Part 2 of the topic 2 session included success cases introduced by each country to increase the understanding of NDE technologies and SHM systems and their possibilities. Part 2 of topic 2 related to the following question:

Do you have any examples of cases in which these technologies have been used successfully to determine a specific bridge-management action? What type of data/information was used for condition assessment of bridges?

- United States presenter—Frank Moon.
- United States presenter—Marybeth Miceli.
- United States presenter—Genda Chen.
- Japan presenter—Mamoru Sawada.
- Japan presenter—Takeshi Miyashita.

Part 3: Bridge-Condition Assessment and Performance Monitoring

Part 3 of the topic 2 session clarified the performance, performance measures, and the relationship between design performance and actual performance by leveraging NDE/SHM technologies.

Summary presentations included the following:

- United States presenter—Hoda Azari.
- Japan presenter—Yoshinobu Oshima.

Open discussion topics included the following:

- Bridge-performance measures used by the bridge authorities.
- Necessary steps to define performance and performance measures.
- Relationship between design performance (i.e., performance requirements or the required load-carrying capacity of a bridge) and actual performance (i.e., performance measures captured by monitoring).

Part 4: Challenges for Cost-Effective Implementation of NDE Technologies and SHM Systems

Part 4 of the topic 2 session identified issues that need to be resolved and challenges that must be overcome for further acceptance, deployment, and implementation of NDE technologies and SHM systems in bridge-condition assessment and performance monitoring.

Summary presentations included the following:

- United States presenter—Hoda Azari.
- Japan presenter—Yoshinobu Oshima.

Open discussion topics included the following:

- Establishing a clear implementation plan to introduce NDE technologies and SHM systems to management.
- Identifying fundamental barriers that preclude the use of NDE technologies and SHM systems in bridge-condition assessment and performance monitoring.
- Identifying stakeholder needs (e.g., policies, specifications, certifications) to accept and implement NDE technologies and SHM systems.
- Identifying how advancements in technologies can overcome the constraints of using NDE technologies and SHM systems.

TOPIC 3: GUIDELINES AND USE OF REFINED NUMERICAL CALCULATIONS FOR DESIGN AND BRIDGE ASSESSMENT

The primary participants for topic 3 are listed in table 3.

Table 3. Primary participants for topic 3.

Last Name	First Name	Affiliation
Marx	Elmer	Alaska DOT*
Zokaie	Toorak	Caltrans
Ger	Jeffrey	FHWA
Zoli	Ted	HNTB Corporation
Murphy	Tom	Modjeski and Masters
Hoshikuma	Jun-ichi	NILIM**
Oshima	Yoshinobu	PWRI
Ono	Kiyoshi	Waseda University
Miki	Tomohiro	Kobe University

*United States lead.
**Japan lead.
PWRI = Public Works Research Institute.

Refined analysis is used in both the United States and Japan to create detailed analytical bridge models. These models consider the effects of complex element behavior, shape effects, geometric nonlinearity, inelastic material properties, and other phenomena not easily or accurately analyzed by conventional hand methods.

The code-specified safety factor or targeted reliability index are determined under the assumption that conventional methods for determining the demand and capacity of bridge members are employed (i.e., the analysis methods and design equations included in the code). When refined methods are used, code-specified safety factors or reliability index may not be achieved.

Advancements in refined numerical analysis are leading to increased use of refined analysis methods in bridge design. Refined analysis allows for more accurate predictions of structural demands and capacity but poses challenges to bridge owners and code developers due to its complexity. Design objectives, code calibration, and results verification need addressing before refined numerical analysis can be fully implemented by designers.

Prior to the workshop, participants from the United States and Japan generated a broad list of topics for consideration. Following preliminary discussions, the list was reduced to nonseismic and seismic-related numerical methods of analysis.

UNITED STATES

Of particular interest to participants from the United States was what types of analyses are considered refined methods. For example, the United States classifies moment-curvature and pushover analysis for seismic applications as refined analyses whereas Japan does not.

Participants from the United States were also interested in how the results of refined numerical analyses are verified in Japan (e.g., peer review or physical model tests), what written guidelines exist, and to what extent bridge owners are involved in the acceptance process.

JAPAN

Of particular interest to participants from Japan was how the target reliability index or safety factor provided in design criteria is ensured when using refined analyses. Japanese design criteria specify that safety factors are set under the presupposition of the analytical method specified in their codes for quantifying demand/capacity of bridge members and the structural details of those members.

Participants from Japan were also interested in the FHWA *Manual for Refined Analysis in Bridge Design and Evaluation*, particularly as it relates to the effect of utilizing refined analysis on reliability, and the verification and the quality control of the refined analysis method.[6]

Based on these interests, participants from Japan wanted to discuss the future of refined analysis and its use in bridge design to satisfy the performance requirements of design specifications.

Topic 3 Session Structure

The topic 3 session included presentations from primary participants followed by open discussions. Primary participants gave short presentations on their respective country's guidelines and use of refined numerical analysis for bridge design and assessment. The presentations were followed by discussions on challenges for implementing refined numerical analysis and topics for future research.

Discussions focused on how refined numerical analyses and related guidelines differ in the United States and Japan. Recent advances in nonseismic guidance (e.g., FHWA *Manual for Refined Analysis in Bridge Design and Evaluation*) were discussed in the first half of the session, while recent advances in seismic analysis and design recommendations (e.g., Caltrans Seismic Design Criteria 2.0) were discussed in the second half of the session.[6,7]

Part 1: Background on Refined Analysis

Part 1 of the topic 3 session included background information on refined numerical analysis methods and an overview of design specifications and construction practices in the United States and Japan. The term "refined methods" was defined and differences in interpretation were clarified to avoid misunderstanding.

Summary presentations included the following:

- United States presenter—Elmer Marx.
- Japan presenter—Jun-ichi Hoshikuma.

There was an open discussion at the end of part 1 of this session.

Part 2: Use of Refined Analyses for Nonseismic Design

Part 2 of the topic 3 session included discussions on topics that were selected based on past email communications, questions and answers, and participant interest. Each topic was discussed for 10 to 15 min.

Summary presentations included the following:

- United States presenter—Tom Murphy.
- Japan presenter—Jun-ichi Hoshikuma.

There was an open discussion at the end of part 2 of this session.

Discussion topics included the following:

- How the target reliability index or safety factor in design specifications are met when utilizing refined analyses.
- Which design parameters should be specified in performance-based design specifications when using refined analyses.
- When and under what circumstances refined analytical methods are recommended.
- How the results of refined analyses are verified and checked.
- Which opportunities exist for collaboration and information exchange.

Part 3: Use of Refined Analyses for Seismic Design

Part 3 of the topic 3 session included discussions on topics that were selected based on past email communications, questions and answers, and participant interest. Each topic was discussed for 10 to 15 min.

Summary presentations included the following:

- United States presenter—Toorak Zokaie.
- Japan presenter—Jun-ichi Hoshikuma.

There was an open discussion at the end of part 3 of this session.

Discussion topics included the following:

- Acceptability of the approach in design specifications to utilize refined analysis methods for quantifying local-site adjusted ground acceleration.
- Examining future uses of refined methods in everyday practice.
- Defining justifiable levels of refined analyses given the uncertainty in the seismic hazard demand.
- Exploring the advances in performance-based seismic bridge design.
- Identifying available opportunities for collaboration and information exchange.

TOPIC 4: INNOVATIVE MATERIALS FOR BRIDGE DESIGN AND CONSTRUCTION

The primary participants for topic 4 are listed in table 4.

Table 4. Primary participants for topic 4.

Last Name	First Name	Affiliation
Khaleghi	Bijan	Washington State DOT*
Chynoweth	Matt	Michigan DOT
Potter	Will	Florida DOT
Saiidi	Saiid	University of Nevada at Reno
Ohsumi	Michio	PWRI**
Shirato	Masahiro	NILIM
Tamakoshi	Takashi	PWRI
Nakamura	Eisuke	PWRI
Miyashita	Takeshi	Nagaoka University of Technology
Ono	Kiyoshi	Waseda University
Miki	Tomohiro	Kobe University

*United States lead.
**Japan lead.
PWRI = Public Works Research Institute.

Although advances in design and construction have historically come about with the advent and availability of new, innovative materials, their acceptance as replacements for traditional materials has been slow. Among the myriad reasons innovative materials are not immediately embraced are that codes and standards may not yet be developed, long-term durability is unknown, fabricators and plants are not set up to handle new materials, high initial costs, and the advent of risk.

Prior to the workshop, participants from the United States and Japan generated a broad list of topics for consideration. Following preliminary discussions, the list was reduced to the differences in the use of innovative materials in bridge construction and repair and rehabilitation in the United States and Japan.

UNITED STATES

Of particular interest to participants from the United States were similarities and differences with Japan's experience dealing with the research, implementation, and use of innovative materials.

In the United States, glass-fiber-reinforced polymer (GFRP) sheets are used mostly for repairs and retrofits of various concrete bridge elements; CFRP is used for pre- and post-tensioned applications, piling applications, and repairs and retrofits of various bridge elements; stainless steel strands are used for prestressing applications; UHPC is used for bridge applications (e.g., connections, full elements, strengthening); flexible fillers (e.g., petrolatum wax) are used for post-tensioning tendon replacement and corrosion protection; and nickel-titanium shape memory alloys (SMAs), engineered cementitious composites, and rubber are used for enhancing seismic performance.

Although these materials have undergone years of research and development, there are still obstacles to their implementation. High costs, a lack of existing specifications, and risk avoidance have contributed to learning curves with the use of each material.

JAPAN

Of particular interest to participants from Japan was how the use of innovative materials fits with existing design codes and specifications in both countries. They were curious about the performance and reliability requirements in these codes and specifications; the performance and reliability requirements for retrofitting/reinforcing existing structural members using innovative materials; and clauses, recommendations, or commentaries in design codes and specifications on how to evaluate the performance and reliability requirements of bridges and structural members made from innovative materials.

In Japan, CFRP sheets are widely used to reinforce and repair structural members. Japan also has a number of pedestrian bridges constructed entirely of FRP. Fiber-reinforced concrete has been used on bridge piers, and Japan has considered the application of UHPC for precast slabs. High-performance steel (i.e., SBHS500-HPS) is listed in *Specifications for Highway Bridges*.[(5)] High cost and lack of performance data are Japan's major obstacles to implementation; evaluating durability is also a problem.

Participants from Japan voiced concern that available codes and specifications, and guidance for innovative materials, are incomplete. Certifying bodies may not be able to incorporate all provisions related to new, innovative materials in specifications, so other institutions (e.g., academia or industry) may need to fill that need. However, any guidance from other institutions is legally nonbinding. Participants from Japan were also interested in what processes are used to define resistance factors in design codes and specifications for structural members that incorporate new materials for design, rehabilitation and repair, and whether minimum requirements for data have been set for establishing resistance factors in both countries.

Participants from Japan noted that there are always insufficient data to evaluate structural reliability, such as the mechanical property of materials, the experimental data for determining load bearing capacity of members, or construction quality, when using new materials.

Topic 4 Session Structure

The topic 4 session included presentations from primary participants followed by open discussions. Primary participants gave short presentations on their respective country's use of innovative materials in bridges. The presentations were followed by discussions on the best applications for new materials, existing and future standards, challenges in implementation, and topics for future research.

Discussions focused on best practices and experience using innovative materials, evaluating the durability of innovative materials, the lack of performance data and test protocols, and requirements and criteria needed for incorporating innovative materials into technical standards.

Part 1: Innovative Material for Bridge Design and Construction

Part 1 and part 2 of the topic 4 session were dedicated to discussing the use of high-performance materials in the United States and Japan.

Summary presentations included the following:

- Stainless Steel and Stainless Rebar—Kiyoshi Ono, Waseda University. A summary of the high corrosion resistance and toughness properties of stainless steel, types of stainless steel (e.g., SUS304 and SUS316) used, engineering properties of stainless steel versus those of conventional steel, applications on bridges, status on design standards, existing gaps in knowledge, and future prospects of the use of stainless steel rebar.
- Innovative Superelastic Materials for Seismic Resiliency and Accelerated Bridge Construction—Dr. Saiid Saiidi, University of Nevada at Reno. Advantages of SMAs; summary of research, development, and implementation in an actual bridge in Washington State; and an update on the current status of SMA research.
- Concrete-Filled Steel Tubes for Accelerated Bridge Construction—Bijan Khaleghi, Washington State Department of Transportation. A summary of research and implementation of concrete-filled steel tubes in bridge projects for piers and deep foundations and for a tubular truss bridge.
- Polyester Concrete Deck Overlays—Sarah Skeen, FHWA. A summary of the use of polyester concrete for deck overlays and application by Caltrans.

There was an open discussion after each country's presentations.

Part 2: Innovative Materials for Bridge Design and Construction

Summary presentations included the following:

- CFRP Repair Method for Corroded Steel Bridges—Takeshi Miyashita, Nagaoka University of Technology. A summary of research conducted to develop a repair method for corroded steel bridge members using CFRP sheets, availability of a technical manual, and performance issues.
- GFRP Reinforced Concrete—Will Potter, Florida DOT. A summary of the history, current status, and planned future of standardization efforts; and use of GFRP concrete with examples of installations, current implementation efforts, and hurdles.
- CFRP Prestressing Concrete Bridge Elements—Matt Chynoweth, Michigan DOT. Michigan's experience with research and deployment of concrete bridge elements prestressed and post-tensioned with CFRP strands as opposed to steel strands.
- FRP Reinforcement in Concrete Structures—Eisuke Nakamura, PWRI. Use of FRP reinforcement in Japan and applications of prestressing cables.

There was an open discussion at the end of part 2 of this session.

SUMMARY AND CONCLUSIONS

TOPIC 1: BRIDGE DESIGN, REHABILITATION, AND RETROFITTING FOR ENHANCED DURABILITY AND PRESERVATION

Both the United States and Japan take a similar approach in developing enhanced durability (i.e., service life) design methods.

Both countries face issues with collecting data of sufficient quality to develop probabilistic factors for durability design. The format and type of data collected are important for proper calibration but are not currently defined. The United States and Japan would both benefit from collaborating on developing data requirements.

There is a gap in establishing a clear link between durability design and subsequent requirements for in-service inspection and maintainability. One proposed solution in the United States is to prepare a full-life durability-design document (i.e., a bridge birth certificate) that defines what bridge-specific inspection and maintenance is expected over a bridge's lifespan. One proposed solution in Japan is to check if the expected maintenance or partial replacement of deteriorated bridge members is feasible after verifying that the method used to ensure durability would actually work as long as predicted. The United States and Japan would both benefit from collaborating on establishing universal guidance so all bridges have similar characteristics for inspectability and maintainability.

The United States and Japan determine chloride loading differently. Japan has a large database of chloride content deposited on 100×100 mm (4×4 inch) anticorrosive specimens (e.g., stainless steel plates) collected in different geographic areas throughout the country. These data allow Japan to establish chloride loading rates in geographic zones for design purposes. In the United States, chloride loading is established by taking concrete cores from an existing or nearby structure and plotting chloride ingress at 1-cm (0.4-inch) depths. The loading is set where the extension of the curve intersects the surface line. Further discussions on the pros and cons of each approach would benefit both countries.

Data collected during routine bridge inspections could be more refined to help owners make better repair and maintenance decisions. The United States relies heavily on inspector experience and recommendations. In Japan, bridges are inspected every 5 yr, and recommended repairs are expected to be completed before the next inspection. Further discussions on justifications for the frequency of inspections and how inspection data are used to determine which bridges need preservation actions would benefit both countries.

Performance data on new products and technologies are also lacking. Establishing methods to quickly and thoroughly test new products and technologies would help both countries.

TOPIC 2: BRIDGE INSTRUMENTATION AND HEALTH MONITORING

Participants from both countries expressed concern about NDE technologies and SHM systems, including reliability requirements, the performance that is captured and evaluated, the development of technology that is focused on practical applications, and the technology evolution.

The following conclusions and recommendations resulted from the topic 2 discussion:

- Diagnosis and assessment by visual inspection can be supported and complemented by NDE technologies and SHM systems.
- NDE technologies and SHM systems are effective if the purpose and target of testing and monitoring is clear.
- NDE technologies are more integrated into current practice in the United States than SHM systems.
- For SHM systems to be valuable, which data are collected and how they will be used must be explicitly defined from the outset.
- The American Society for Nondestructive Testing has NDE certifications and guidance, but currently only for steel.
- There are currently no SHM guidelines or standards available in the United States aside from guidance related to the installation of sensors and data processing/analysis.
- Although SHM systems have evolved, the value of such technologies has not been demonstrated.
- Of the many monitoring technologies available, it remains unclear which are most practical and useful.
- The full benefits of SHM systems will not be realized without a clear monitoring strategy and a proper evaluation model.

TOPIC 3: GUIDELINES AND USE OF REFINED NUMERICAL CALCULATIONS FOR DESIGN AND ASSESSMENT

During discussions on the use of refined analyses utilization in each country, additional topics of interest beyond the intended theme were discussed. Engineers from the United States and Japan discussed postconstruction bridge evaluation (e.g., load ratings and overload permitting), which likely would not have been possible in the traditional "lectern session" format used in previous workshops.

The following conclusions and recommendations resulted from the topic 3 discussion:

- Agree on a unified definition of "refined numerical analysis methods."
- Finalize and publish the *Manual for Refined Analysis in Bridge Design and Evaluation*.(6)
- Use refined numerical methods to develop better, more accurate approximate methods.
- Develop a prioritized list of hurdles to implementation so guidance can be developed.
- Exchange tsunami research and design guidelines (e.g., Oregon DOT is leading a pooled fund study on tsunami bridge loads, and Japan has specifications for structural planning of bridges subjected to tsunami effects).(8)
- Exchange design strategies for bridges affected by difficult-to-predict loads (e.g., fault displacement).

- Hold a session at future joint workshop on load rating and evaluating existing bridges.
- Share bridge design codes and specifications with practicing bridge design engineers to exchange information on design assumptions utilized and on needs for additional written guidance.

TOPIC 4: INNOVATIVE MATERIALS FOR BRIDGE DESIGN AND CONSTRUCTION

The United States and Japan were interested in the use of innovative materials for bridge design and construction. Both countries faced issues with collecting sufficient performance and cost data, the development and analysis of which would benefit both the United States and Japan. Obstacles faced by both countries for implementing innovative materials for bridges included costs, lack of past implementation and performance data, monopoly of intellectual property, construction difficulty, and lack of technical standards. Success stories of using innovative materials for bridges, as described by presenters, included implementing innovative superelastic materials in a bridge in Washington State and applying polyester concrete deck overlays in California.

The following conclusions and recommendations resulted from the topic 4 discussion:

- Prepare a unified approach for the use of innovative materials and technologies in bridges.
- Research, develop, and implement SMAs for seismic resiliency.
- Use numerical methods to properly model how innovative materials behave in bridge designs.
- Prioritize the implementation of innovative materials in funded projects for research and to help develop design specifications and standards.
- Share research and outcomes from projects using innovative materials.
- Exchange and compare current and future bridge design specifications and standards.
- Provide opportunities for bridge designers and engineers to discuss design assumptions and the need for additional guidance not covered in specifications.
- Develop performance-based design specifications for new and existing bridges and structural members.
- Develop recommendations and commentaries in design specifications on evaluating new materials.
- Share success stories of using innovative materials in bridges.
- Review and share research results and use of concrete-filled tube in accelerated bridge construction.
- Summarize the history, current status, and planned future use of GFRP concrete.

APPENDIX A. WORKSHOP PARTICIPANTS

The workshop participants from the United States are listed in table 5.

Table 5. Participants from the United States.

Last Name	First Name	Title	Affiliation
Abu-Hawash	Ahmad	Chief Structural Engineer	Office of Bridges and Structures, Iowa DOT
Agrawal	Anil	Professor	Department of Civil and Environmental Engineering, The City College of New York
Alampalli	Sreenivas	Director	Structure Management Bureau, New York State DOT
Azari	Hoda	Nondestructive Evaluation Research Program Manager	Turner-Fairbank Highway Research Center, FHWA
Chen	Genda	Professor and Abbett Distinguished Chair in Civil Engineering	Department of Civil, Architectural, and Environmental Engineering, Missouri University of Science and Technology
Chynoweth	Matt	Chief Bridge Engineer	Bureau of Bridges and Structures, Michigan DOT
Duwadi	Sheila Rimal	Principal Research Engineer	Turner-Fairbank Highway Research Center, FHWA
Foley	Richard	Construction Manager	Division of Bridges, Caltrans
Ger	Jeffrey	Senior Structural Engineer	FHWA
Goto	Jun	Infrastructure Consultant	Metal Fatigue Solutions, Inc.
Hida	Sue	Assistant State Bridge Engineer	Caltrans
Johnson	Bruce	Bridge Engineer	Oregon DOT
Khaleghi	Bijan	Bridge Engineer	Washington State DOT
Kozy	Brian	Principal Bridge Engineer	FHWA
Marx	Elmer	Senior Bridge Design Engineer	Alaska DOT
Miceli	Marybeth	President	Miceli Infrastructure Consulting
Moon	Frank	Professor	Department of Civil and Environmental Engineering, Rutgers University

Last Name	First Name	Title	Affiliation
Murphy	Tom	Vice President, Chief Technology Engineer	Modjeski and Masters
Ostrom	Tom	Deputy Division Chief, State Bridge Engineer	Division of Engineering Services, Caltrans
Pezeshpour	Mina	Office Chief (Acting), Bridge Design Manager	Division of Engineering Services, Caltrans
Potter	Will	Assistant State Structures Design Engineer	Marcus H. Ansley Structures Research Center, Florida DOT
Richter	Cheryl	Director, Office of Infrastructure Research and Development	Turner-Fairbank Highway Research Center, FHWA
Saiidi	Saiid	Professor	Department of Civil and Environmental Engineering, University of Nevada at Reno
Sanders	David Howard	Greenwood Department Chair and Professor	Department of Civil, Construction, and Environmental Engineering, Iowa State University
Shen	Jia-Dzwan	Senior Bridge Engineer – Seismic Specialist	FHWA
Skeen	Sarah	Division Bridge Engineer	FHWA
Wang	Dayi	Senior Bridge Engineer – Steel Specialist	FHWA
Yen	W. Phillip	Structural Engineer	International Association of Bridge Earthquake Engineering
Zokaie	Toorak	Chief, Seismic Guidance Branch	Office of Earthquake Engineering, Caltrans
Zoli	Theodore Peter	National Chief Bridge Engineer	HNTB Corporation

The workshop participants from Japan are listed in table 6.

Table 6. Participants from Japan.

Last Name	First Name	Title	Affiliation
Hoshikuma	Jun-ichi	Head, Kumamoto Earthquake Recovery Division	NILIM, MLITT
Miki	Tomohiro	Associate Professor	Department of Civil Engineering, Kobe University
Miyashita	Takeshi	Associate Professor	Department of Civil and Environmental Engineering, Nagaoka University of Technology
Nakamura	Eisuke	Senior Researcher	Innovative Materials and Resources Research Center, PWRI
Nozaka	Katsuyoshi	Professor	Department of Civil and Environmental Engineering, Ritsumeikan University
Okada	Takao	Senior Researcher	NILIM, MLITT, Infrastructure, Transport, and Tourism Bridge and Structures Division
Ono	Kiyoshi	Professor	Department of Civil and Environmental Engineering, Waseda University
Oshima	Yoshinobu	Senior Researcher	CAESAR, PWRI
Ohsumi	Michio	Chief Researcher	CAESAR, PWRI
Sawada	Mamoru	Senior Researcher	CAESAR, PWRI
Shirato	Masahiro	Head of Bridge and Structures Division	NILIM, MLIT
Tamakoshi	Takashi	Chief Researcher (Bridges)	CAESAR, PWRI

CAESAR = Center for Advanced Engineering Structural Assessment and Research; MLIT = Ministry of Land, Infrastructure, Transport, and Tourism.

APPENDIX B. PREWORKSHOP QUESTIONS

Prior to the workshop, both countries exchanged the following questions that helped develop topic areas and sessions and provided talking points for discussion relevant to participants' interest.

DECISIONMAKING, INSTITUTIONAL LAYOUT, AND USE OF SPECIFICATIONS AND GUIDELINES

1. Who has the authority to approve bridge-related policy and design standards in each country? Does the authority change across the various segments of each nation's highway system (e.g., U.S. interstates, State routes, local roadways)?

2. Who has the authority to approve exceptions for bridge-related policy and design standards in each country? Does the authority change across the various segments of each nation's highway system (e.g., U.S. interstates, State routes, local roadways)?

3. How does funding affect the decisionmaking regarding the adherence to policy and standards or bridge design, construction, and maintenance?

4. How does asset ownership (e.g., public, private, public–private partnership) affect decisionmaking in each country?

5. What materials, design specifications, and recommended calculation methods are available for repair, reinforcement, or retrofit design in the United States?

6. Who determines minimum requirements for the safety and reliability (i.e., allowable loads and resistance factors) of a structure during construction?

TOPIC 1: BRIDGE DESIGN, REHABILITATION, AND RETROFITTING FOR ENHANCED DURABILITY AND PRESERVATION

United States to Japan

1. Two large bridges, Tappan Zee Bridge in New York, and the Ohio River Downtown Crossing in Louisville, KY, have had a formal design prepared for 100-yr service life using the concepts and procedures in *fib Bulletin No. 34*.[3] Have any major bridges in Japan been designed using the *fib Bulletin No. 34* procedures?

2. *fib Bulletin No. 34* describes three methods of service-life design: full probabilistic, deemed to satisfy, and avoidance. Most of the practices in the United States are based on deemed to satisfy when avoidance is not practical.[3] Full probabilistic analysis is only used for reinforced concrete, typically on major bridges. Explain how these methods are used or understood in Japan.

3. A fourth method of service-life design that has been discussed in the United States is the partial factor method. This method has calibrated load and resistance factors for various environmental conditions and materials or protection treatments. The problem with developing this method in the United States is a lack of quality data on condition or performance of bridge elements using various materials and protective treatments under various environmental conditions. Does Japan have detailed quality condition and performance data that could be used to calibrate load and resistance factors for service-life design?

4. In the pursuit of enhanced durability and extended service life, some States (in the United States) have specified nontraditional materials, such as high-strength stainless steel bars, for post-tensioning applications in lieu of galvanized or epoxy-coated steel. Are there examples of such use in Japan? If so, what is the performance history?

5. UHPC is gaining acceptance in the United States and its use has been expanded to bridge deck overlays to enhance durability and extend service life. Has Japan used UHPC for bridge deck overlays? If so, what were Japan's experiences with performance, cost, and product availability from multiple suppliers?

6. In the northern region of the United States, bridge deck deterioration is a significant concern due to the extensive use of deicing chemicals. To improve the durability and service life of bridge decks, many States have invested in bridge deck overlays, sealers, coatings, corrosion-resistant reinforcing bars, and other high-performance materials. Furthermore, the United States has attempted to eliminate or minimize deck expansion joints to prevent water intrusion into supporting girders and substructure components by using integral and semi-integral abutments. What strategies has Japan used to protect both superstructure and substructure components from deicing chemicals?

7. Early-age cracking of concrete bridge decks is a common occurrence in the United States, which negatively impacts durability and service life. Although numerous studies have been conducted on this subject, practical solutions have not been reached. The combination of material properties, cementitious content, boundary conditions, restraining forces, and curing practices—along with environmental factors—have been identified as potential contributors. Improvements in these areas, along with the use of internal-curing concrete (i.e., expanded shale) have been suggested to overcome this problem. Has Japan experienced such phenomena? Please provide examples of successful remedies that were used in Japan.

8. Japan has one of the longest use histories of dehumidifying cables on suspension bridges. What are Japan's experiences, lessons learned, and any changes that would be made if Japan were starting over?

9. For bridges in coastal areas, do you categorize environmental exposure conditions based on distance from the ocean? For bridges that pass over saltwater, how does Japan treat the different areas of piers (e.g., underwater, water level, above water level, superstructure) that are exposed to marine salts? Does Japan have different approaches to concrete material design or concrete cover dimensions based on location?

10. Some State DOTs have been using stainless steel reinforcement or FRP to extend the service life of bridges exposed to marine salts or heavy deicing salts for up to 20 yr. The United States also has up to 20 yr of experience using silane or other similar concrete sealers that slow down the intrusion of chlorides. The United States believes these protection strategies have a higher initial cost but are cost effective over the life of a bridge. Does Japan have data showing the effectiveness of such treatments?

11. Has Japan developed a definition for the service life of a bridge? If so, how is service life defined?

12. What typical maintenance activities do bridge owners perform to extend the life of bridges in Japan? Is it common to replace the reinforced concrete decks of bridges during their service lives? Are joints and bearings routinely replaced? Are there any proactive steps taken to preserve bridge components prior to needing replacement? The United States is trying to develop effective methods of preserving bridge components to extend their service lives to reduce the need for replacement.

13. The FHWA Long-Term Bridge Performance (LTBP) program conducted a survey of State DOTs and found the following bridge elements most in need of developing better preservation techniques in priority order from highest to lowest need:

    a. Untreated bridge decks.
    b. Treated (or protected) bridge decks.
    c. Prestressed/post-tensioning systems.
    d. Steel coatings.
    e. Joints.
    f. Bearings.

14. What bridge elements are most in need of further improvement to develop better preservation techniques? Does Japan have a program similar to the FHWA LTBP program where the performance of bridge elements is measured using NDE technologies to quantify deterioration and service life extension after various preservation actions?

15. When designing bridges or elements of a bridge for enhanced service life, the United States believes there is a risk of wasting money on bridges located in regions where traffic demands and growth cannot be reliably forecasted for 100 yr so that a 100-yr design can be planned and executed accordingly. A recent study sponsored by the National Transportation Research Board and conducted by Iowa State University shows that a majority of bridges replaced in the United States were for functional reasons (e.g., inadequate number of traffic lanes, narrow lane or shoulder width, low vertical clearance) and not for deteriorated conditions. Does Japan try to assess future functional

needs when deciding what level of enhanced service life should be included in a bridge design?

Japan to United States

1. In the AASHTO *LRFD Bridge Design Specifications*, does durability or service-life design include a concept of designing maintainability and inspectability?[(2)]

2. In the AASHTO *LRFD Bridge Design Specifications*, are there any criteria or clarifications about the required condition level of structural elements in terms of functionality or strength that matches with service limit state or strength-limit design?[(2)]

3. Is *Service Life Design for Bridges* a legally binding technical requirement or directive associated with U.S. specifications or standards?[(1)]

4. Why is the target service-life design 100 yr in *Service Life Design for Bridges*?[(1)]

   a. What was the conventional target service-life design—75 yr?
   b. What are the reasons to make it longer than a reference period of 75 yr to estimate design loads?
   c. Is there a clear difference in predicted or empirical load carrying capacity (LCC) when designing with a target service-life design of 100 yr and that of 75 yr?

5. What is the required or minimum performance and its level of reliability and durability in the AASHTO *LRFD Bridge Design Specifications*.[(2)] In the AASHTO *LRFD Bridge Design Specifications*, what are the relationships between bridge strength and durability performance?[(2)]

6. Why are two-girder systems avoided in the United States? When using two-girder systems, is the load factor increased? What if the service-life design for fatigue was 200 yr or longer—would the United States still hesitate to use two-girder systems?

   a. Will the reliability in structural safety will decrease with deterioration?
   b. Will the reliability in bridge safety against deterioration be secured by giving a sufficient redundancy or avoiding using fracture-critical members?
   c. Is redundancy or robustness required only for abnormal live loads in the AASHTO *LRFD Bridge Design Specifications*?[(2)]

7. Does the United States predict a longer target service life or increased reliability for connections or gussets than other bridge members?

8. Do environmental exposure conditions and wheel loads vary from part to part—even within a bridge subsystem—because the individual structural details (e.g., position of stiffness plates, drainage systems, spacing between elements) are provided by designers because specifications and standards do not provide guidance? If yes, how is reliability in durability design made more equal between different bridge systems or parts of a bridge system?

9. Are there any ideas in the AASHTO *LRFD Bridge Design Specifications* or owner's discretion/standards to enhance the incentive to multilayer protections in durability design?(2)

10. Do live-load deflection criteria influence bridge durability and user comfort? Are there any strategies to omit live-load deflection criteria from design specifications or practice (i.e., use other durability calculation methodologies instead)?

11. Does the AASHTO *LRFD Bridge Design Specifications* set a minimum requirement of maintainability and inspectability or are they considered deemed to satisfy?(2)

12. Are there any problems using prestressed concrete (PC) box girders in regions where deicing salts are used? There is a greater risk of delamination on a concrete bridge deck that is prone to frost damage and exposed to lots of deicing salts. Moreover, replacing an upper flange in a PC box girder bridge changes stress distributions, which should be avoided. Do some DOTs in cold regions avoid using PC box girders or require concrete bridge deck waterproofing when using PC box girders?

13. Which is preferred in PC bridges: inner or outer tendons? When comparing inner and outer tendons, there is a tradeoff between the severity of exposure conditions and the ease of inspection and replacement. Are there any criteria, standards, or recommendations to evaluate inner or outer tendons?

14. Hanger cables, bearings, and bridge deck concrete are theoretically replaceable. Which structural elements are considered better designed or more reliable in meeting the target service-life design?

    a. To provide structural details to facilitate to replace them even if something unexpected happens during the target design service-life of bridge system.
    b. To provide a longer target design service-life to such individual structural elements than the target design service life of the bridge system.

15. Does the concept of inspectability and maintainability in the AASHTO *LRFD Bridge Design Specifications* include provisions for hazardous situations, such as earthquakes and floods?(2) How should design specifications address inspectability and maintainability for hazardous situations?

16. Does the AASHTO *LRFD Bridge Design Specifications* clarify the general and comprehensive principles of performance requirements for durability or show only specific design equations with load factors and design constants for fatigue and chloride ingress without a universal target reliability regardless of material or environmental actions?(2)

17. There is a fatigue-limit state in the AASHTO *LRFD Bridge Design Specifications*.(2) However, fatigue is sensitive to local stress distributions and welding quality. How does the AASHTO *LRFD Bridge Design Specifications* evaluate the target reliability and resistance factor for a fatigue-limit state?(2)

18. Does the AASHTO *LRFD Bridge Design Specifications* consider particular target reliability in the accumulation of chloride ingress or durability design of concrete members against chloride ingress?(2) Can a relevant concrete cover depth be decided from bridge to bridge to achieve the target reliability index against chloride ingress?

19. Is the United States looking to change target reliability indices in durability design to avoid the distress of fatigue and chloride ingress with the extents of inspectability, maintainability, or redundancy?

    a. Has the United States studied how the AASHTO *LRFD Bridge Design Specifications* rates the extent or fulfilment of inpsectability and maintainability?(2)

20. Are there any comprehensive guidelines, rules, test protocols, or certification systems to ensure durability with repeated loads and corrosion in deck systems, bearings, expansion joints, or connections of precast concrete segments? What are the terms of use regarding durability?

21. Has the United States studied reinforcement or repair methods of steel or concrete members using chemical adhesives? Is it prospective to develop any test protocols for evaluating expected service life or identifying relevant terms of use for different deteriorated states and environmental conditions? Is the United States likely to develop inspection methods to evaluate the soundness or residual strength of adhesives during service life?

22. Is it difficult to design a bridge so all surfaces and elements are accessible and can be visually inspected? Do bridge owners request bridges be designed so surfaces can be inspected by NDE technologies (e.g., cameras)?

23. During repairs and retrofits, existing elements are sometimes covered or wrapped by steel plates or carbon-fiber sheets, making it difficult to see the existing elements. Do bridge owners ask designers to make it feasible to inspect elements by any means? Are there any guidelines in the AASHTO *LRFD Bridge Design Specifications* or any other standards about inspectability when repairing or retrofitting existing bridges?(2)

24. Are there any discussions or studies on changing the suggested inspection frequencies of the National Bridge Inspection Standards (NBIS) with the implementation of *Service Life Design for Bridges*?(1) Are there any other suggested improvements in durability design guidelines, specifications, or standards?

25. What improvements to the AASHTO *LRFD Bridge Design Specifications* would be necessary to reduce the suggested inspection frequencies of the NBIS for regular, scour, fatigue or detailed inspections?(2) When using NDE technologies and SHM systems for detailed inspections, would it be feasible to skip a regular inspection every few years?

26. What are the main purposes of implementing element-based inspection and service-life design for the short- and midterm, respectively?

27. Are there any other research projects or discussions regarding a future revision of the NBIS to better align suggested inspection frequencies or methods with improvements to service-life design? If yes, what ideas have been raised? If no, are there any ideas to simultaneously reduce inspection costs and risks of bridge collapse?

28. An idea has been discussed in Japan that inspections would be omitted for particular structures and elements, such as small bridges, culverts, expansion joints, and roadside features (e.g., signs and light poles), and they would be replaced at a particular frequency or designated service life ensured by bridge owners. Have State DOTs had similar discussions?

TOPIC 2: BRIDGE INSTRUMENTATION AND HEALTH MONITORING

United States to Japan

1. What bridge-management processes (i.e., inspection and evaluation) are used in Japan?

2. What bridge-related performance measures are used by the bridge authority?

3. What bridge-management tools are used in Japan?

4. What advanced technologies (e.g., NDE technologies and SHM systems, remote sensing, unmanned aerial systems, artificial intelligence, virtual reality) has Japan incorporated into bridge management in the last 10 yr?

5. How do each of the advanced technologies fit into Japan's bridge-management process and the way performance measures are determined?

6. What is the basis for deploying a specific technology (e.g., cost–benefit analysis)? Does Japan account for the lifecycle cost of technology being deployed?

7. What types of data are used to assess the condition of bridges (e.g., qualitative versus quantitative, directly or indirectly with data interpretation)?

8. Are data gathered and processed in real or near-real time?

9. How are data used (i.e., are data complimentary to visual inspection, preservation, and maintenance strategies or bridge management)?

10. What common detection/measurement technologies are used to collect data?

11. Do the common detection/measurement technologies involve automation features?

12. Are data gathered from NDE technologies processed in real or near-real time?

13. How are data used (i.e., are data complimentary to visual inspection, preservation, and maintenance strategies or bridge management)?

14. Does Japan find value in using NDE technologies both in the short and long term (i.e., seismic and nonseismic purposes)?

15. What agency curates, stores, and manages collected data?

16. Are NDE technologies used at the bridge system level or bridge element level or both? Why?

17. Does Japan monitor bridges periodically or continuously?

18. Is the cost of technology implementation incorporated into the original design and construction cost?

19. Does Japan have any provisions or standards to guide the use of NDE technologies?

20. Do bridge owners have in-house expertise on the use of NDE technologies or rely on contractors/consultants?

21. Is there any national or agency-level certification process for the use of NDE technologies?

22. What are the challenges of implementing NDE technologies and how has Japan overcome these challenges?

23. What policies or existing technologies are necessary for increased acceptance and wider application of new technologies?

24. How is Japan managing data? How are data incorporated into overall bridge management?

Japan to United States

1. Is there a clear definition of healthy state or health in terms of bridge management that can be captured by monitoring?

2. What is the definition of SHM (i.e., what is the difference between NDE technologies and SHM systems, monitoring, and inspections)?

3. Is there a clear road map of using monitoring technologies bridge management?

4. What is the purpose of SHM in terms of bridge management?

5. Are there any success stories of NDE technologies and SHM systems being used in bridge management? What is the purpose of tension monitoring for PC tendons and how is it practical in bridge management?

6. Are NDE technologies and SHM systems used in performance-based monitoring? If not, does the United States intend to establish such performance-based monitoring?

7. What is the relationship between bridge performance and SHM (i.e., how is structural condition associated with design performance)?

8. Could SHM systems replace visual and contact inspections (e.g., sounding)?

9. If SHM systems replace human activity, who takes responsibility for the results? Is full automation possible? How reliable should SHM systems be to replace visual and contact inspections?

10. Are there intentions to change the conventional bridge inspection and monitoring process, which consists mainly of visual inspections and using NDE technologies?

11. Are data obtained from conventional inspections enough for accurate diagnosis?

12. How can the limitations of interval inspections be overcome to reduce risks (i.e., immediately identify a sudden phenomenon) and prevent hazards (i.e., identify the moment a performance indicator reaches its threshold due to deterioration)?

13. What performance indicators can be used to judge whether or not a structure is healthy?

14. How is the United States filling the gap between design assumptions and measurable performance?

15. Outstanding issues to be resolved include the following:

    a. The control level in management should be expressed in technical or physical indices (threshold and baseline)
    b. The gap between the design assumption and actual reality should be expressed in technical or physical indices
    c. Cost effective measurement should be realized
    d. Creating the structures whose performance can be monitored and controlled by SHM and its design method also should be created.

16. Have monitoring technologies developed successfully?

17. How does the United States use the results of BWIM in bridge management? Is BWIM successfully applied to management?

18. Is monitoring cost effective?

TOPIC 3: GUIDELINES AND USE OF REFINED NUMERICAL CALCULATIONS FOR DESIGN AND ASSESSMENT

United States to Japan

1. What types of analyses are considered refined (i.e., is using a grillage model to determine live-load distribution in multigirder bridges considered a refined analysis method)?

2. When are refined analysis methods most commonly used? Are refined analysis methods used for all cable-supported bridges?

3. Are refined analysis methods commonly used for conventional (e.g., girder-slab) highway bridges?

4. What guidance (e.g., national standards, research-generated recommendations, in-house experience and expertise) is available for engineers using refined numerical methods?

5. How do static analysis methods compare to dynamic analysis methods for conventional and significant structures (i.e., are linear methods used for nonseismic loads and nonlinear methods used for seismic demands)?

6. What are the limitations of refined numerical analysis methods and can these limitations be addressed through research?

Japan to United States

1. Can the United States provide background information on refined analyses?

2. What is the direction of refined analyses and their use in satisfying the performance requirements of design specifications?

3. Can you provide examples of the refined analyses?

4. How are refined and conventional analyses defined in bridge design specifications in the United States?

5. What should Japan include in design specifications when refined analyses are standardized, including any check points and notices for the refined analyses?

6. Are there any quality controls for refined analyses?

7. When verifying the load-carrying performance of bridges, the load and resistance of the superstructure have been estimated based on measurement data and experimental results for each element of the superstructure, respectively. Does the United States consider the inelastic properties of bridge elements and the distribution effects of loads on those elements in the structure when estimating the load-carrying capacity of the entire structure?

8. To what situations are refined analyses applied during bridge design? When refined analyses are applied, how does the United States ensure safety factors specified in design specifications?

9. Is it possible to standardize advanced analyses, such as thermal or chloride-penetration analyses to verify durability? How can Japan specify the thermal gradient for thermal analyses in design specifications? How can Japan specify the input of chloride-penetration analyses?

10. Steel bridges can be designed economically when nonlinear finite element analysis is used on compact composite sections and high-performance steel. Has this design approach become more common in the United States?

11. Is it an acceptable design approach of a steel superstructure that the required strength is ensured by the entire structure even though some elements behave in an inelastic manner?

12. When nonlinear finite element analysis is used in bridge design, is the applicability of the finite element analysis or verification with experimental results reviewed?

13. The effects of nonlinear finite element analysis modeling may be significant. Does the United States specify the details of nonlinear modeling in design specifications?

14. In the design of steel elements, a limit state is generally represented by a stress. The stress limit has historically been estimated based on experimental data from reliability studies, the nominal stress derived from the beam theory, and the ductility of the steel. How the limit stress should be evaluated is controversial when demand analysis is performed using finite element analysis because a comparison between the principal stress or the von Mises stress derived from the finite element analysis and the conventional limit stress are meaningless. Does Japan need to estimate other stress limits based on past test data associated with the principal stress or the von Mises stress?

15. Has finite element analysis been applied to concrete sections where stress concentration may develop (e.g., anchorage areas of PC bars)?

16. If applied, how does the United States identify the details of finite element modeling in design specifications? Since finite element analysis calculates a local stress, how can Japan estimate stress limits to ensure required safety factors are met? Does the United States specify resistance factors for the local stress of anchorage areas of PC bars?

17. In the bridge design specifications of Japan, a modifier for structural modeling uncertainties is determined for partial factors to provide incentive for the refined geological investigation of the ground around the bridge because an effect of the modeling uncertainties of the ground properties on reliability of the capacity of bridge foundation is greatly significant and thus mitigation of those uncertainties may improve reliability of the design. This approach may also be one of options of the refined analysis.

18. Is there research on an analytical approach for estimating ground movement for local seismic sites? Is such analysis accepted for the seismic design of bridges in the United States?

19. Are there any refined analyses to estimate bridge redundancy? If yes, how is the load for estimating the bridge redundancy specified in specifications in the United States? Are requirements for the refined analysis of the bridge redundancy clarified in specifications in the United States?

TOPIC 4: INNOVATION MATERIALS FOR BRIDGE DESIGN AND CONSTRUCTION

United States to Japan

1. What is the status of innovative materials in Japan?
2. Is the use of innovative materials in Japan backed by research? Are there any updates to Japan Society of Civil Engineers design specifications?
3. Are there any examples of implementing innovative materials?
4. Are there any obstacles to implementing innovative materials, such as availability, cost, or technical expertise?
5. Are there any lessons learned?
6. Are there any needs for further research?
7. What design and material specifications are available for innovative materials?
8. What decisionmaking tools are used when choosing and using innovative materials?
9. Are lifecycle cost analyses performed?
10. How has durability been evaluated in certain innovative materials (e.g., FRP, stainless steel, fiber-reinforced concrete, UHPC, fillers for post-tensioning systems)?
11. How are implemented innovative materials monitored to assess performance/benefits?
12. How does the industry participate in the development of innovative materials?
13. How are projects selected in terms of using innovative materials, seismic considerations, long-term prestress losses, estimation of jacking forces given deviated tendons, and environmental-reduction factors, and to what fraction of specified tensile strength of prestressing steel (f_{pu}) (0.60, 0.70, 0.80) is Japan stressing innovative materials?

Japan to United States

1. What innovative materials have been used in the United States?
2. Was there any research into the use of innovative materials?
3. Were there any obstacles to implementing innovative materials, such as availability, cost, or technical expertise?
4. Are there any lessons learned?

5. Are there any needs for further research?

- The performance and reliability requirements for whole bridges or structural members for new bridges in the design codes.
- The performance and reliability requirements for the retrofit/reinforce of existing structural members that uses a new material in the design codes.
- Any clauses or recommendations or commentaries in the design codes on how to evaluate if a new material or structural member with a new material will meet the performance and reliability requirements.
- Provisions on the use of innovative materials in technical standards.
- Evaluation methods and evaluation items of innovative materials.
- Design system to promote dissemination of innovative materials.

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