Synthesis Report for United States—Japan Bridge Engineering Workshops

(Commemorating a Thirty-Year Partnership)

Federal Highway Administration
U.S. Department of Transportation

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Executive Summary

For the past 30 years, the United States and Japan have brought together bridge experts to share and build knowledge on innovations in bridge engineering. Convening every year – alternating between the two countries – these U.S.-Japan Bridge Workshops represent a vibrant community of practice that has helped improve our understanding and management of these critical elements of our road transportation networks. The success of these workshops is credited to the shared leadership provided by the U.S. Department of Transportation's Federal Highway Administration (FHWA); the Public Works Research Institute (PWRI) of the Japanese Ministry of Land, Infrastructure, Transport, and Tourism; and the U.S. and Japanese workshop chairs.

This synthesis report summarizes the results of the information exchanges. The report will be presented at the upcoming 30th U.S.-Japan Bridge Engineering Workshop in commemoration of the successful collaboration and partnership between these two countries.

Accomplishments of the Workshops

The annual U.S.-Japan Bridge Engineering Workshops provide a venue for bridge engineers, practitioners, and researchers to exchange information on current research initiatives and innovative technologies and practices in bridge engineering. The workshops are generally held over a two and one-half day period, with an additional half-day program provided for government-to-government discussions on policy issues. The workshops have covered a variety of topics, such as: bridge design and analysis, codes and specifications for new design and retrofit of structures, seismic engineers, damage assessment and predication. The programs also include site visits to significant bridge construction sites and facilities. In addition to serving as a vehicle for communications and technology exchanges, the workshops are a platform for cooperation and collaboration among governmental agencies, universities, and private entities in the United States and Japan. Some of the notable achievements of the workshops include:

- Approximately 900 Japanese and American technical experts have taken part in the workshops over the 30-year period.[1] Participants often attended more than one annual workshop and average attendance for each meeting exceeded 50 participants.
- The workshops are successful in promoting information exchange and knowledge building between the two countries. Over1,000 technical papers have been presented at the workshops and published in formal proceedings.
    - Topics discussed at the workshops covered almost the entire field of bridge engineering.
    - Of the 1,054 technical papers, 423 papers focused on the seismic behavior of bridges; 353 papers discussed design, analysis, maintenance, inspection, and strengthening; and the remaining 278 papers were on other topics such as wind, construction, materials, management, geotechnical engineering, and experimental investigation.

[1] The attendance of the workshops is based on invitation. The number of unique attendees is 900.

- The workshops also facilitated cooperative research projects, collaboration, networking, personnel exchanges, reconnaissance efforts, and management of extreme events between the United States and Japan.
    - Since 1992, the FHWA has initiated 3 primary research projects to mitigate infrastructure losses due to earthquakes. They are: "Seismic Vulnerability Studies of New and Existing Highway Construction," "Seismic Vulnerability Studies of Highway Systems," and the "SAFETEA-LU Seismic Research Program."[2] The research findings from these projects have been presented at the workshops.
    - Following the 2011 Great East Japan (Tohoku) Earthquake, Japanese and U.S. reconnaissance teams jointly inspected 11 bridge sites to gather first-hand information on bridge performance during this major earthquake. The reconnaissance effort provided technical experts with a better understanding of the impacts of major earthquakes on bridges.
    - Joint reconnaissance efforts were also conducted to inspect other bridges damaged by severe earthquakes such as the 1994 Northridge Earthquake in the United States and the 1995 Hyogoken Nanbu (Kobe) Earthquake in Japan. The reconnaissance teams worked closely to collect crucial data on bridge performance. Numerous reports were published to convey lessons learned to State Departments of Transportation (DOTs) and private practitioners.
    - A pilot study initiated by the FHWA, as well as discussions at recent workshops, contributed to the initiation of a number of research programs by State DOTs such as Caltrans and Oregon DOT. These studies have addressed knowledge gaps related to load and resistance factor design for seismic bridges.

Benefits of the Workshops

The workshops have produced a number of benefits that have affected the way that both countries practice bridge engineering and have deepened cooperation and collaboration among technical experts and practitioners. There are seven primary areas that have benefited:

- Knowledge sharing and technology exchange.
- Cooperative research programs.
- Collaboration.
- Professional networking.
- Personnel exchanges and training.
- Reconnaissance.
- Response to and recovery from devastating events.

a. **Sharing knowledge and exchanging technologies for mutual benefit.** Significant benefits have been realized by both countries through sharing and exchange of technologies, leading to advances in knowledge and practice in bridge engineering. For example, U.S. bridge engineers have shared the following information with Japanese workshop participants:

[2] SAFETEA-LU stands for "Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users."

- Seismic retrofitting measures.
- Protective systems.
- Ductile structure design.
- New construction concepts such as Accelerated Bridge Construction (ABC).
- Load and Resistance Factor Design and Resistance Rating.

In return, the United States has benefited from Japanese information exchanges on a number of technologies and practices including the following:

- Seismic retrofitting measures.
- Protective systems.
- Tsunami design procedures.
- Recovery technology and emergency planning for earthquakes and tsunamis.

The sharing of technologies developed by each country independently is mutually beneficial as it can provide for different approaches to meeting similar challenges and technical issues encountered in bridge engineering. For example, both the United States and Japan developed seismic retrofitting and seismic isolation technologies at almost the same time. Through sharing and exchanges at workshops, U.S. and Japanese bridge engineers identified potential technological advances, some of which were implemented into practice. Japanese retrofitting measures, for example, were transferred and successfully implemented in high seismicity areas such as those found in the states of California, Washington, and Oregon. These retrofitting measures include restrainers, steel and concrete jackets, as well as Fiber-reinforced Polymer (FRPs) jackets for shear strengthening and ductility enhancement of columns. Additional state-of-the-art and state-of-the-practice technologies exchanged between the two countries include those related to wind design for long-span bridges, bridge inspection, assessment, maintenance, advanced materials, and bridge management.

b. **Cooperative research programs.** Another outcome from the annual workshops is the ability for the United States and Japan to work closely on jointly-funded research opportunities. Engaging in cooperative research projects has facilitated collaboration among researchers in both countries, allowing for exchange of research findings and sharing of state-of-the-art practices. These cooperative programs have been extremely effective and successful, leading to the:

- Development of draft guidelines for experimental verification of seismic performance of bridges, including quasi-static cyclic loading tests and shake table tests for bridge columns.
- Preparation of a comparative study of U.S. and Japanese seismic design of highway bridges, seismic control systems, and seismic testing protocols.
- Establishment of a collaborative research program to explore improvements to the numerical modeling of tsunami effects, as well as development of design procedures and validation of these procedures using wave basin experiments.

c. **Collaboration.** In addition to ongoing cooperative research programs, seven additional collaborative workshops focusing on specialty areas such as earthquake protective systems and seismic retrofitting techniques were convened in the 1990s. Exchanges of technologies at these workshops significantly accelerated the adoption of protective systems in both countries, and the improvement and implementation of retrofit strategies.

d. **Professional networking.** The annual workshops have provided a networking platform through which professionals have interacted on a continuous basis. The professional relationships formed between U.S. and Japanese participants have continued to produce improvements in the field of bridge engineering. These relationships have provided a strong foundation for new generations of bridge engineering professionals who continue to be mentored by more experienced professionals in the discipline.

e. **Personnel exchanges and training.** In addition to professional networking, another valuable benefit resulting from the workshops is the personnel exchange program. Under this initiative, engineers and researchers have been invited to stay in the other country from one week to one year to exchange technical information and perform joint studies. A total of 23 engineers and researchers participated in the personnel exchange program between 1983 and 2014. The personnel exchange opportunities allowed these individuals to become familiar with current practices in the other country and to establish strong, long-lasting personal connections.

f. **Reconnaissance.** The workshops have been extremely successful in facilitating extensive joint reconnaissance efforts of severe earthquakes that occurred in the United States and Japan, including the Northridge Earthquake (California) in 1994, the Hyogoken Nanbu (Kobe) Earthquake in 1995, and the Great East Japan (Tohoku) Earthquake in 2011. Similar joint reconnaissance efforts have also been made with significant earthquakes that occurred elsewhere, such as the Maule Earthquake (Chile) in 2010. Research programs on the duration effects of strong ground motion and the effects of skew on seismic response were established in the United States after the Maule and Great East Japan Earthquakes. In addition, as a result of productive discussions on tsunamis at a recent U.S.-Japan Bridge Engineering Workshop, new research programs were undertaken in the United States including a series of research projects spearheaded by state DOTs such as Caltrans and Oregon DOT, as well as a pilot study conducted by the FHWA.

g. **Response and recovery from devastating events.** Sharing experiences on prompt response and recovery from devastating earthquakes and tsunamis is extremely valuable in preparing for, responding to, and recovering from these natural disasters. U.S. engineers and public officials have benefited significantly from their Japanese counterparts' lessons-learned. Similarly, the United States has shared its experiences with recent earthquakes and hurricanes. Most importantly, exchanges at past workshops have significantly contributed to mitigating the loss of human life and property in extreme events.

Suggestions and Recommendations for Future Workshops

The extensive cooperation and close collaboration between the United States and Japan has created synergies for future work in promoting research innovation and sharing technologies and resources. Both countries have a common interest in building on past achievements in order to enhance future workshops.

This synthesis report provides suggestions and recommendations for possible enhancements to these annual workshops, as summarized in Table ES-1 below. Suggestions and recommendations focus on six areas: (1) sharing and exchange of technologies, (2) cooperative research programs, (3) collaboration in specialty areas, (4) expanding professional networking, (5) outreach and enlarging the attendee base, and (6) funding sources for workshops. Table ES-1 highlights objectives and suggested actions for each subject area. For example, the objective for the area of sharing and exchanging of technologies is to continue sharing and exchanging technologies. By recognizing that the workshops have made remarkable achievements in this area, the suggested actions include continuing to hold face-by-face meetings, exploring other cost-effective online media, gathering recommendations from other bridge professional organizations, and exploring new topics that may be interesting to the public and private sectors.

This synthesis report recognizes that challenges such as geographical differences, language barriers, time differences, and limited funding support may hinder the effectiveness of interaction and communications among the workshop attendees. It has not been easy to overcome these difficulties in the past, and it will continue to be a challenge in the future. With continued leadership and resolve of key stakeholders, along with improved funding mechanisms, it is believed that both the United States and Japan will realize tremendous benefits for years to come.

Table ES-1. Suggestions and recommendations for future workshops.

Subject Area	Objective	Suggested Action
Sharing and exchange of technologies	Continue sharing and exchanging technologies	• Continue to hold face-to-face meetings and explore cost-effective video web conferencing and online webinars • Gather suggestions from other bridge-related professional organizations • Explore new topics including public-private partnerships, concepts such as damage or maintenance-free structure design, precast/prestressed curved concrete girders in highway bridges, and high performance construction materials such as rapid setting grouts
Cooperative research programs	Expanding joint research	• Explore potential funding to support more joint research projects • Establish a communication mechanism for sharing resources, determining topics, and enhancing personnel involvement
Collaboration in specialty areas	Expanding collaboration in specialty areas	• Hold collaborative meetings on a regular basis and encourage publication of research reports in specialty areas
Expanding professional networking	Using the Internet to expand networking activities	• Encourage participants to use social media for professional communications • Establish an Internet forum for workshop participants
Outreach and enlarging the attendee base	Expanding the attendee base	• Conduct outreach activities to attract more participants, including young members from the public and private sectors

Funding for workshops in the United States	Expanding funding sources beyond the FHWA	• Establish a more permanent funding mechanism for the annual workshop by
		  ○ Exploring funding from state DOTs
		  ○ Attracting private companies to exhibit at the workshops

Chapter 1. Introduction

Under the leadership of the U.S. Department of Transportation's Federal Highway Administration (FHWA) and the Japanese Ministry of Land, Infrastructure, Transport and Tourism's Public Works Research Institute (PWRI), the annual U.S.-Japan Bridge Engineering Workshop has been held alternately in the United States and Japan since 1984. The 30th annual workshop will be held in the United States in 2014. In past workshops, bridge engineers and other participants from both countries have discussed issues related to bridge design, construction, maintenance, seismic engineering, regulations, policy, and many other topics. The workshops have not only been a vehicle for communications and technology exchange, but have also become a platform for cooperation and collaboration among governmental agencies, universities, and industry in the United States and Japan. This report summarizes the achievements and benefits of the U.S.-Japan Bridge Engineering Workshop in commemoration of its 30th anniversary.

This chapter starts with a brief overview of the historical context and development of the workshops, technology exchanges, and collaborations. It is then followed by a discussion of the objectives and the organization of the report, as well as the approach taken for developing the report.

1.1 Background: Historical Development of the Bridge Workshops

The United States and Japan have a long history of cooperation in technology exchanges. Prior to establishing the bridge workshops, the United States and Japan established the U.S.-Japan Cooperative Program in Natural Resources (UJNR), as a mechanism of cooperation, in January 1964. Under the UJNR, a special program was dedicated to scientific cooperation between the U.S. and Japan (*1, 2*). There were a total of 18 panels convened under the UJNR's scientific program, including a panel on wind and seismic effects.

Panel on Wind and Seismic Effects

The Panel on Wind and Seismic Effects was established in 1969, five years after the inception of the UJNR program (*3*). The goals of the panel were to (1) encourage, develop, and implement the exchange of wind and seismic technologies; (2) develop stronger technical links between the two countries; and (3) conduct joint research and cooperative programs, and exchange guest researchers and equipment.

The PWRI of Japan's Ministry of Land, Infrastructure, Transport and Tourism provided the Japanese chair for the panel. The Japanese panel consisted of approximately 50 members representing seven national research organizations, ministries, and agencies. The National Institute of Standards and Technology of the U.S. Department of Commerce provided the U.S. chair. The U.S. panel comprised about 50 representatives from appropriate U.S. governmental organizations.

Task Committee on Wind and Earthquake Engineering for Transportation Systems

At the 13th joint panel meeting held at the PWRI in Tsukuba Science City, Japan on May 19-22, 1981, it was agreed to form a Task Committee on Wind and Earthquake Engineering for Transportation Systems. This new committee was charged with carrying out joint research between the United States and Japan in wind and earthquake engineering for transportation systems. The initial activities of the Task Committee focused on wind resistance and seismic technologies related to traffic facilities. The U.S. DOT's FHWA was the lead agency for the United States and chaired the Task Committee. Delegations for the meetings consisted of bridge engineering researchers and practitioners representing local, state, and federal governmental agencies; academia; industry; and consultants.

U.S.–Japan Bridge Engineering Workshop

At a Task Committee meeting held in 1983, the U.S.–Japan Bridge Engineering Workshop was proposed and planned. As a result, the first U.S.-Japan Bridge Engineering Workshop was held at the PWRI in Tsukuba Science City, Japan, in 1984. Since 1984, the workshops have been held at alternating locations in the United States and Japan on an annual basis, except for the year 1986. Figure 1 highlights the historical development and establishment of the bridge workshops. To date, a total of 29 workshops have been held at the following locations:

- Tsukuba Science City, Japan (15 workshops).
- United States locations, including Buffalo, Chicago, Lake Tahoe (hosting two workshops), Minneapolis, New Orleans, Pittsburgh, Portland, St. Louis, San Diego, San Francisco, Seattle, South Lake Tahoe, and Washington, D.C. (14 workshops).

Face-to-face meetings. The annual workshops typically include two and one-half days of face-to-face meetings in order to exchange research and technologies. Attendees from both countries present technical papers during these meetings. Figure 2 displays the number of participants at each annual workshop. Overall, nearly 900 individual participants have attended these workshops over the past 30 years. Some participants have attended multiple workshops. As shown in Figure 2, the highest number of participants, 93 attendees, was recorded at the 17th workshop held in 2001. Additionally, there were three workshops that had more than 80 attendees: the 7th (1991), 13th (1997), and 15th (1999) workshops. In general, the following observations can be made regarding trends for workshop participation:

- The number of attendees from the United States varied from 11 to 40 at each of the prior 29 workshops, while the number of Japanese participants ranged from 12 to 73 people.
- On average, each workshop had 54 participants; 21 participants were from the United States and the remaining 33 attendees were from Japan.

- The host country typically had more attendees than the guest country.

- When the workshops were held in Japan between the 7th (1991) and 17th (2001) workshops, the number of Japanese participants for each workshop, about 60 to 70 attendees, was more than the other workshops held in Japan.

Figures 3 to 6 present the group photos of attendees at early workshops. The group photos of attendees were taken at the second workshop in San Francisco, USA, in 1985 (Figures 3 and 4). Figures 5 and 6 show the group photos at the fifth workshop in Tsukuba Science City, Japan, and the sixth workshop in Lake Tahoe, USA, respectively.

Since 1984, a total of 1,054 papers have been presented and published in the workshop proceedings. Figure 7 illustrates the number of papers that were presented at each workshop. The figure shows the following trends in the number of papers presented at the workshops:

- The U.S. attendees presented 7 to 27 papers at various workshops, while the Japanese participants published 9 to 30 papers.

- On average, each workshop had 36 papers: 17 papers by the U.S. participants and 19 papers by the Japanese attendees.

- Host country attendees presented more papers than guest country attendees.

- In the workshops held between 1997 and 2008, the numbers of published papers each year were higher than the average number of papers published per year for all workshops.

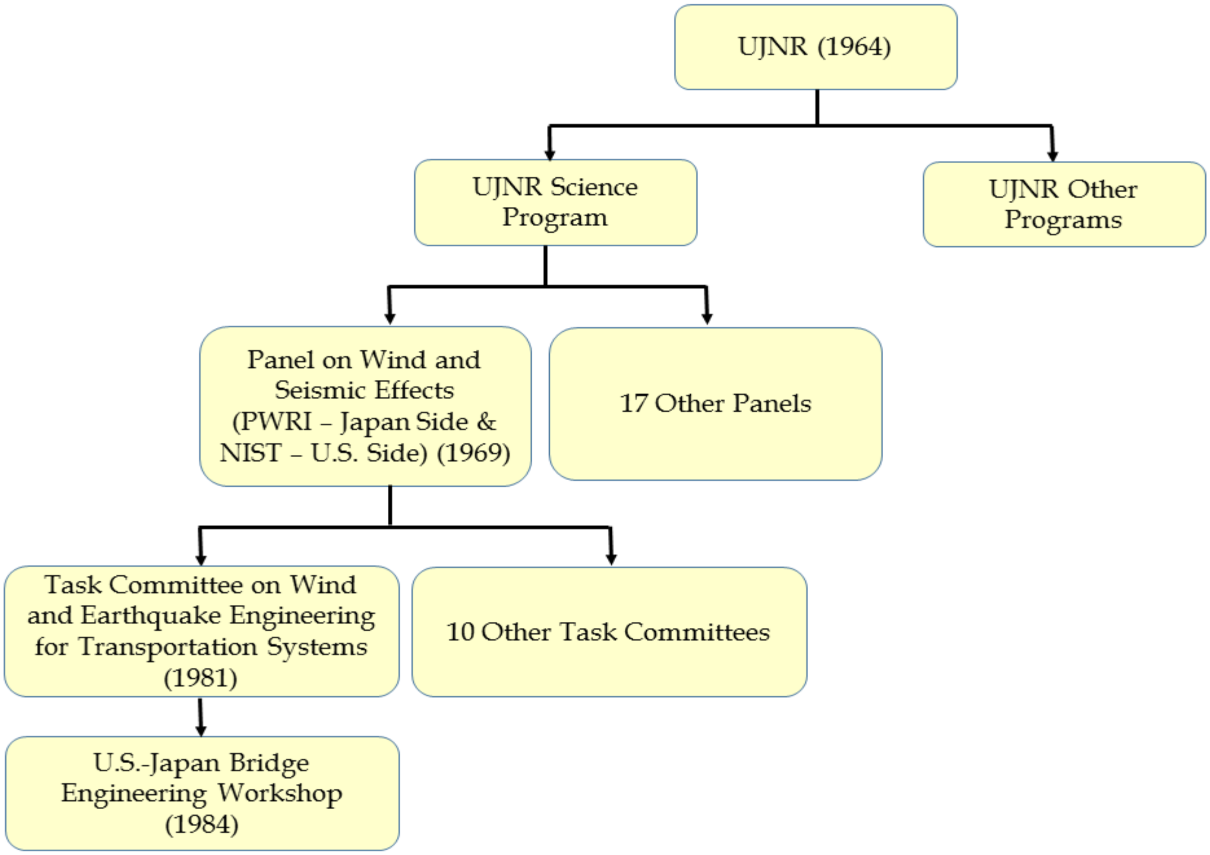

Figure 1. Illustration of the historical development of the U.S.-Japan Bridge Engineering Workshop.

Technical site visits. The workshops also included technical site visits such as visiting significant bridges and facilities. The technical site visits at the very early workshops typically occurred at significant bridges such as cable-stayed and suspension bridges. For example, workshop attendees visited the Golden Gate Bridge, one of the iconic landmarks in San Francisco, USA, at the second workshop in 1985 (Figure 8). The technical site visits in recent years also involved important facilities such as airports and structures laboratories at several universities. Table 1 lists the technical site visits held at the recent four workshops between 2010 and 2013: two site visits were held in the United States and two visits were held in Japan as part of the workshop activities. Table 1 also lists the purpose of each technical site visit.

In 2010 and 2012, there were two technical site visits held in the United States. For example, one of the technical site visits was held in Oregon in 2012. The workshop attendees visited the ODOT Woodburn Weigh-in-Motion (WIM) Station, where participants were briefed on the truck weight permit and truck weight management program. The attendees also visited the Structures Laboratory at the Oregon State University and several bridges including the Yaquina Bay Bridge, the Spencer Creek Bridge, and the Millport Slough Bridge. Discussions at these technical site visits focused on tsunamis including calculated tsunami loads on a couple of bridges in Oregon; tsunami mitigation of tidal waves; tsunami wave basin experimental simulations;

tsunami modeling; and a potential pooled fund study with California, Hawaii, Washington, and Alaska.

Table 1 also lists two technical site visits held in Japan in 2011 and 2013. U.S. workshop participants visited the Kanto and Tohoku regions of Japan in 2011. They visited the Kiyosu Bridge and the Eitai Bridge, where they discussed a long-term bridge management plan for old bridges. They traveled to the Katsushima area and discussed technologies on how to improve seismic performance. The U.S. workshop attendees also visited a number of damaged bridges due to the Great East Japan Earthquake, including the Arakawa Wangan Bridge, the Koizumi Oh-hashi, the Kesen Oh-hashi, the Osaragi Bridge, the Kameda Oh-hashi, and the Kamata Oh-hashi.

Government-to-government bridge engineering meetings. In addition to the technical site visits, half-day government-to-government bridge engineering meetings were held after the workshops. The meetings were designed for government bridge engineers from both countries to exchange information on technical and policy issues relating to implementing new technologies in an informal environment.

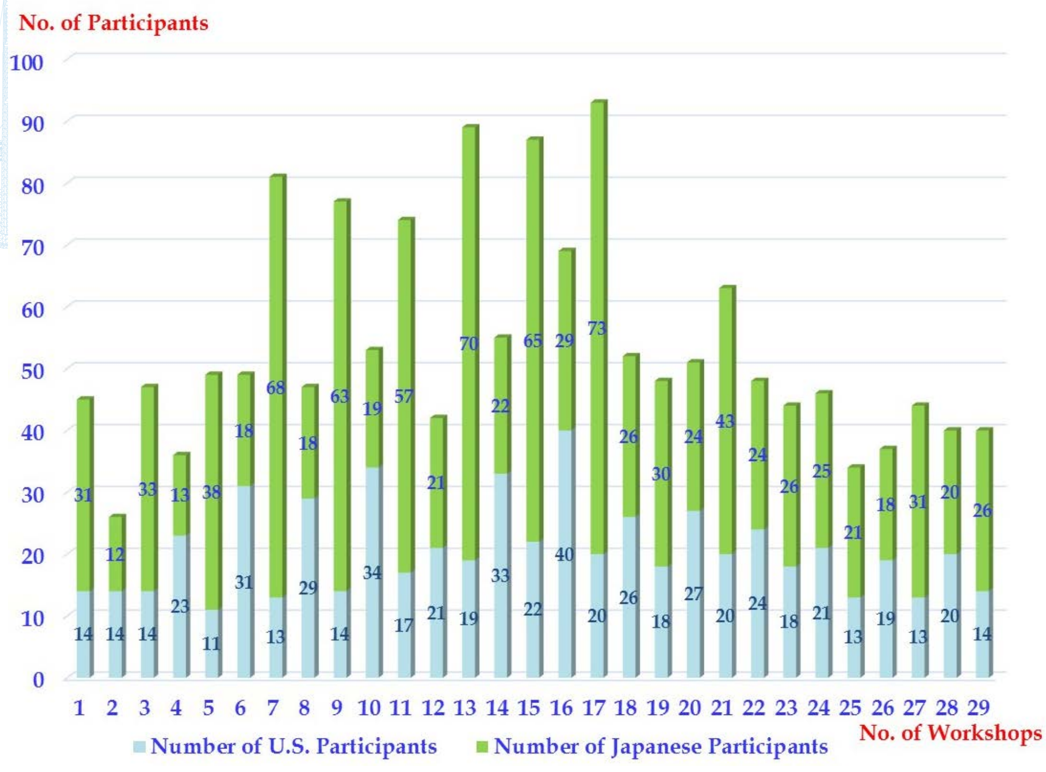

Figure 2. Number of participants by workshop.

Figure 3. Group photo at the second workshop.

Figure 4. Attendees at the second workshop.

Figure 5. Group photo at the fifth workshop.

Figure 6. Group photo at the sixth workshop.

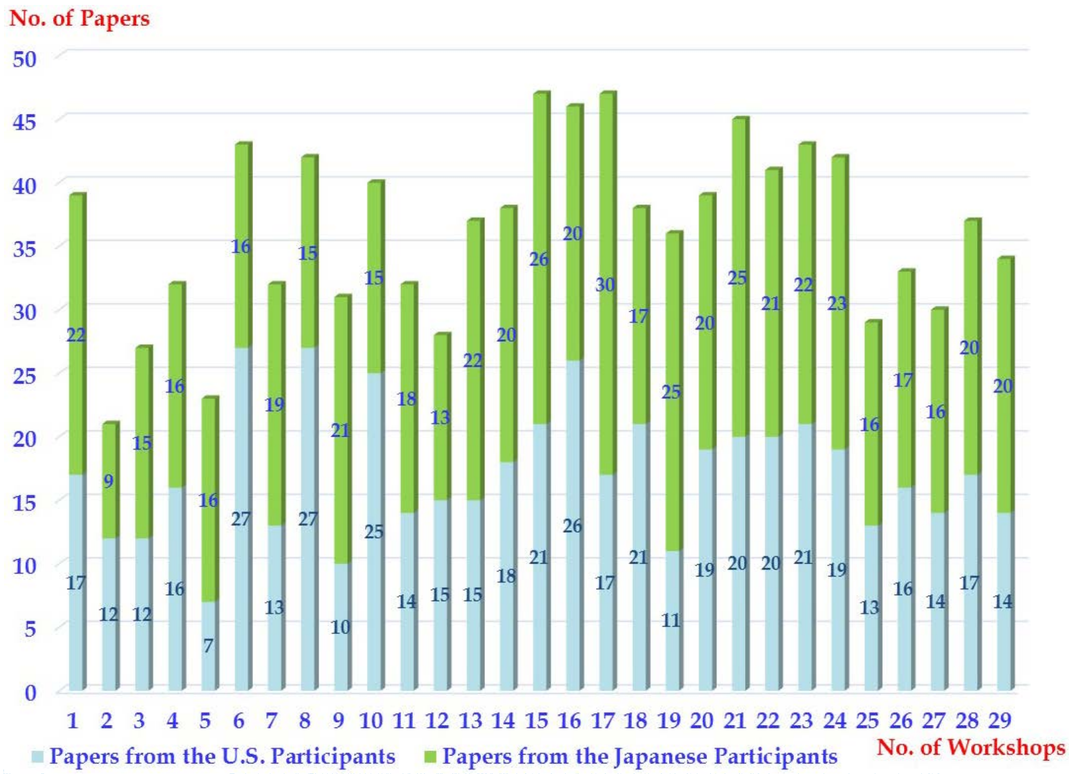

Figure 7. Number of papers presented at the workshops.

Figure 8. Technical site visit of the Golden Gate Bridge at the second workshop.

Table 1. Technical site visits held at the recent four workshops between 2010 and 2013.

Year	Technical Site Visits	Purpose of Technical Site Visits
2010	Louisiana, USA • I-10 Twin Span Bridge • John James Audubon Bridge • LA1 Relocated Project • Movable bridges	• New bridge design and construction after Hurricane Katrina • Design-build • Design and construction of movable bridges
2011	Kanto and Tohoku, Japan • Kiyosu Bridge and Eitai Bridge • Katsushima Area • Arakawa Wangan Bridge • Koizumi Oh-hashi, Kesen Oh-hashi, Osaragi Bridge and Kameda Oh-hashi • Kamata Oh-hashi	• Long-term bridge management plan for old bridges • Improvement of seismic performance • Damaged bridges due to the Great East Japan Earthquake
2012	Oregon, USA • ODOT Woodburn Weigh-in-Motion (WIM) Station • The Structures Laboratory at the Oregon State University • Yaquina Bay Bridge • Spencer Creek Bridge • Millport Slough Bridge	• Truck weight permit and truck weight management program • Tsunami loads on Oregon bridges and potential pooled fund study with California, Hawaii, Washington, and Alaska • Tsunami modeling • Tsunami mitigation on tidal waves • Tsunami wave basin experimental simulations
2013	Kansai region, Japan • Tokushima Airport • Kameura Viaduct • Oh-Naruto Bridge • Chamagawa Bridge • Akashi Kaikyo Bridge • Higashi-Kobe Oh-hashi • Dojima Oh-hashi	• Seismic design and retrofit of bridges • Tsunami effects on bridges • Bridge maintenance • Bridge inspection techniques

1.2 Technology Exchange and Collaboration

The U.S.-Japan Bridge Engineering Workshops have brought together bridge engineers and researchers annually to discuss various topics related to bridge engineering. The workshops have covered a variety of topics including bridge design and analysis, construction, inspection, maintenance, strengthening, codes and specifications for new design and retrofit of structures, seismic engineering, damage assessment and predication, wind and wave forces due to hurricanes and tsunamis, geotechnical engineering, management, and high-performance materials.

The U.S. and Japanese researchers have articulated the need for collaborative research and development to enable more evolvable technological improvements in bridge engineering. The annual workshop enables the United States and Japan to work closely on joint funding opportunities and facilitate collaboration among U.S. and Japanese researchers. Leaders of both countries recognize that the workshops have brought an increasing number of benefits.

Aside from collaboration, another valuable benefit resulting from the workshops is the personnel exchange program. Through this initiative, 23 engineers and researchers were invited to stay in the other country for a period of one week to one year, between 1983 and 2014, in order to exchange technical information and perform joint studies (Appendix II).

1.3 Objective and Organization of the Report

The objective of this synthesis report is to summarize and document the information exchanges between Japan and the United States in the area of bridge technology as a result of the Bridge Engineering Workshops held over the past 29 years. The report also includes recommendations for future development of this highly successful program. The report is organized in the following manner with contents specified below:

- Chapter 2—State-of-the-art technologies exchanged in the workshops: provides an overview of topics addressed in the workshops, and discusses specific topics that were frequently mentioned in the workshops.
- Chapter 3—Accomplishments and benefits: reviews the accomplishments and benefits achieved through the workshops.
- Chapter 4— Suggestions and recommendations: presents recommendations to improve sharing and exchange of technologies, cooperative research programs, specialty area collaboration, formulated professional networking, outreach, and funding for the workshops.

This report will be presented at the 30th anniversary meeting of the U.S.-Japan Bridge Engineering Workshop to be held in the United States in 2014.

1.4 Approach Taken for Developing the Report

For this report, a multifaceted approach was taken, including review of materials from past workshops, a survey of past workshop attendees, and interviews with selected personnel identified throughout the report preparation process. The project team developed a survey questionnaire and a list of interview questions as part of the scope of this project.

Review materials. An extensive review of materials from past workshops was conducted, including review of the references provided by the FHWA, PWRI, and other parties. The references include a summary document by Dr. W. Phil Yen on current activities hosted by UJNR and MLIT/FHWA (*3*); workshop proceedings (*4*); two reports on the 30th joint meeting of the U.S.-Japan Panel on Wind and Seismic Effects by Richard Wright and Yasutake Inoue; and an article prepared by Bruce Johnson at the Oregon DOT for *Public Roads* magazine (*5*). See Appendix I—Bibliographical References for details. The workshop proceedings provided the primary references for this report, as they include published papers, lists of attendees, and descriptions of the technical site visits.

Survey. To obtain feedback from past workshop attendees, a survey was conducted by email to gather input on attendees' experienced benefits, comments, and suggestions for future workshops (Appendix III). The survey questionnaire was emailed to all attendees, and responses from U.S. and Japanese attendees were received. The responses are summarized and incorporated into the narrative throughout this report.

Interviews. Interviews were conducted with selected key personnel to obtain their personal in-depth views on the workshops (Appendix IV). Individuals selected for interviews included Dr. W. Phil Yen, the U.S. chair; Ms. Agnes R. Vélez, the FHWA's Project Manager for the report (*6*); Dr. David Sanders, the U.S. organizer of the workshops at the University of Nevada–Reno (*7*); and Dr. Ian Buckle, an active workshop participant at the University of Nevada–Reno (*8*). In-person interviews were conducted with Dr. Yen and Ms. Vélez at the FHWA, and phone interviews were conducted with Drs. Sanders and Buckle. Additionally, Mr. Hideaki Nishida, the Japan secretary for the workshop, responded to interview questions by email on behalf of Mr. Hiroshi Matsuura, the Japan chair, and other participants at the PWRI including Dr. Shigeki Unjoh and Dr. Jun-ichi Hoshikuma (*9*).

Chapter 2. State-of-the-Art Bridge Technologies Exchanged in the Workshops

The annual workshop provides an excellent opportunity for sharing and exchange of state-of-the art technologies. Professionals from both countries meet and discuss important topics in bridge engineering. The sharing and exchange of technologies results in effectively advancing the knowledge of bridge engineering and also efficiently taking advantage of the combined resources available. Each workshop covers a number of topics that are of interest to workshop participants from both countries. Bridge technologies that have been discussed extensively and exchanged at past workshops include seismic effects; maintenance, inspection, and strengthening; design and analysis; wind; construction (including Accelerated Bridge Construction and design-build); materials; management; geotechnical engineering; and experimental investigation. This chapter highlights and describes the major topics that have been covered at past workshops.

All the major topics reviewed in this chapter were examined and discussed in a total of 1,054 papers, which were presented at the workshops and published in workshop proceedings. By performing an extensive review of the workshop proceedings, those papers were analyzed and categorized to examine the frequency of discussions on various topics. Table 2 presents the specific topics, number of papers corresponding to an individual topic, and percentage of total number of papers presented at past workshops. Approximately 40 percent of the papers focused on seismic effects; 18 percent on maintenance, inspection, and strengthening; 16 percent on design and analysis; 7 percent on general topics; 7 percent on wind; 4 percent on construction; and the remaining 9 percent on miscellaneous topics including materials, management, geotechnical engineering, and experimental investigation. Figure 9 illustrates the percentages of papers on several major topics presented at all past workshops.

Table 2. Topics, number of papers, and percentage of total number of papers presented at the workshops.

Topic	# of Papers	% of Total # of Papers
Seismic effects	423	40%
Maintenance, inspection, and strengthening	188	18%
Design and analysis	165	16%
General	76	7%
Wind	70	7%
Construction	39	4%
Materials	36	3%
Management	30	3%
Geotechnical engineering	21	2%
Experimental investigation	15	1%

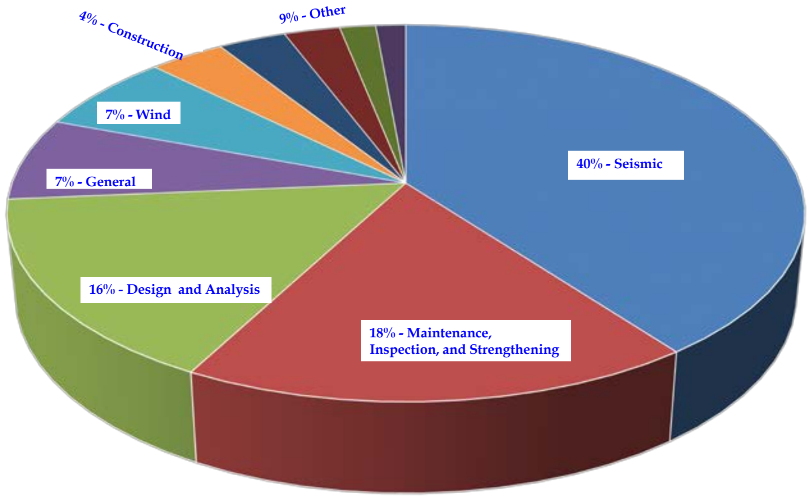

Figure 9. Percentages of papers of various topics in all past workshop proceedings.

In this section, five major topics frequently discussed at the workshops are reviewed and summarized. These five topics are (1) seismic effects; (2) maintenance, inspection, and strengthening; (3) design and analysis; (4) wind; and (5) general topics, construction, and materials. Most of these topics have been discussed in the most recent five workshops held between 2009 and 2013 (Table 3). The common interests relevant to each topic from both the United States and Japan are addressed in this report. Relevant papers from the workshop proceedings are cited to summarize the latest developments of the bridge technologies.

2.1 Seismic Effects

Seismic effects topics are extremely important in bridge engineering because seismic events are potential hazards to human life and bridge structures. Both the United States and Japan are located in the Pacific Rim and face similar challenges due to seismic hazards. It is worth pointing out that damaging earthquakes are rare, and learning from earthquakes is time-consuming. Therefore, sharing and exchange of knowledge and technologies on bridge behavior and performance due to earthquakes is extremely valuable. That is the reason why the seismic topics are the most frequently discussed and visited subjects throughout the workshops. When a significant earthquake occurs, it typically becomes the focus of subsequent workshops. Researchers and engineers share and exchange observations on bridge damage; information on the bridges' structural performance; evaluation of existing practices of design, analysis, and detailing; and suggestions for future improvement. As a result of close cooperation between the United States and Japan at past workshops, there have been joint reconnaissance efforts on a number of severe earthquakes including the Northridge Earthquake (California) in 1994, the Hyogoken Nanbu (Kobe) Earthquake in 1995, the Maule Earthquake (Chile) in 2010, and the Great East Japan (Tohoku) Earthquake in 2011 (*3*). Table 4 summarizes relevant information for these four major earthquakes that were visited by the reconnaissance teams. Figures 10 to 15 illustrate various types of bridge damage due to the Northridge Earthquake, the Hyogoken Nanbu Earthquake, and the Maule

Earthquake. The damage included collapsed bridge spans or sections, buckling of steel girders, abutment wall shear failure, and flange damage in concrete girders.

Figure 10. Collapsed bridge section of westbound Santa Monica Freeway due to the Northridge Earthquake.

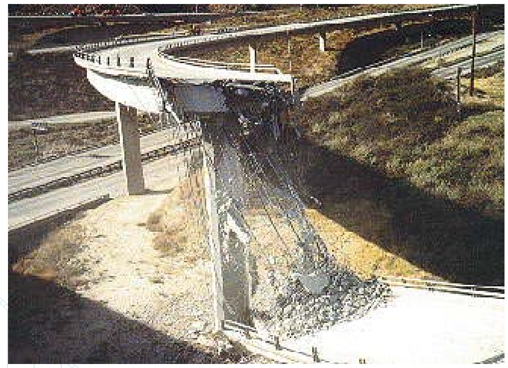

Figure 11. Collapsed connector structure at the Golden State Freeway due to the Northridge Earthquake.

Figure 12. Failure of the Piltz Bridge due to the Hyogoken Nanbu Earthquake.

Figure 13. Buckling of steel girders due to the Hyogoken Nanbu Earthquake.

Figure 14. Abutment wall shear failure in the Chada Bridge due to the Maule Earthquake.

Figure 15. Girder bottom flange damage in the Chada Bridge due to the Maule Earthquake.

The most recent Tohoku Earthquake, also known as the Great East Japan Earthquake, struck the northeast coastal area of Japan and created tsunamis on March 11, 2011. It had a magnitude of 9.0 and was the most powerful earthquake ever recorded to have hit Japan (*4*). Approximately 200 highway bridges and numerous railroad bridges were damaged due to the effects of strong ground motion, tsunami inundation (Figure 16), and soil liquefaction. The damage included span unseating, foundation scour, ruptured bearings, column shear failures, and approach fill settlements. Several photos are included to illustrate the various damage caused by this earthquake. Figure 17 shows the damaged columns in the Nakasone Viaduct. Figure 18 illustrates the damaged piers of the JR Rail Viaduct at the Tsuya River. Figure 19 presents the ejected roller bearing and permanent longitudinal movement at a pier of the Yuriage Bridge.

To collect significant first-hand information on bridge performance due to the Great East Japan Earthquake, a U.S. reconnaissance team led by the workshop's U.S. chair, Dr. Phil Yen, comprising six bridge researchers and engineers, visited Japan in 2011. The U.S. reconnaissance team was supported by the Japan-side task committee, including the Japanese chair, Mr. Tetsuro Kuwabara, and worked closely with the PWRI staff. The team visited 11 bridge sites in Japan from June 2, 2011 to June 6, 2011. They performed a post-earthquake investigation of the performance of the bridges and evaluated the structural damage. The joint reconnaissance efforts on the Great East Japan Earthquake were significantly instrumental and beneficial for increased understanding of the impacts of major earthquakes on bridges. As a result, research programs have been initiated and are under way by workshop participants to study the duration effects of strong ground motion and tsunami loads. A number of reports have been published in order to bring to light the newly learned lessons to bridge engineers at state DOTs and other private practitioners.

In addition to joint reconnaissance efforts on earthquakes, there has been a tremendous amount of sharing and exchange of technologies related to seismic effects in past workshops. For example, the FHWA has initiated three primary research projects to mitigate the infrastructure loss due to earthquakes, including Seismic Vulnerability Studies of New and Existing Highway Construction, Seismic Vulnerability Studies of Highway Systems, and the SAFETEA-LU Seismic Research Program since 1992. The research findings from these projects have also been exchanged at the workshops.

Table 3. List of primary topics in the recent five workshops between 2009 and 2013.

Workshop	Primary Topics
25th (Year 2009)	• Earthquake case histories • Inspection and management • Accelerated Bridge Construction • Remedial work and partial replacement • Maintenance • Seismic performance evaluation • Seismic retrofit
26th (Year 2010)	• Bridge evaluation • Seismic engineering • New construction methods • Accelerated Bridge Construction • Chile Earthquake • Bridge damage • Maintenance and management strategies
27th (Year 2011)	• Great East Japan Earthquake • Tsunami effects • Management and maintenance • Load and strength evaluation • Design and analysis • Seismic engineering • Construction
28th (Year 2012)	• Seismic effects • Assessment • Loads • Tsunamis • General
29th (Year 2013)	• Seismic and tsunami effects • Maintenance • Inspection • Retrofit and repair • Design • Construction

Table 4. List of recent earthquakes involving reconnaissance efforts.

Name	Date	Location	Magnitude	Losses
Northridge Earthquake, CA in 1994	January 17, 1994	Northridge, CA, USA	6.7	• 61 people were killed • About $20 billion was lost due to infrastructure damage
Hyogoken Nanbu (Kobe) Earthquake in 1995	January 17, 1995	Awaji Island, Japan	6.9	• Over 5,000 people were killed • About 9.9 trillion yen was lost due to infrastructure damage
Maule (Chile) Earthquake, in 2010	February 27, 2010	Maule region, Chile	8.8	• About 550 people were killed or missing • $30 billion was lost due to infrastructure damage
Great East Japan (Tohoku) Earthquake in 2011	March 11, 2011	Tohoku region, Japan	9.0	• Nearly 20,000 people were killed or missing • About 16.9 trillion yen was lost due to infrastructure damage

Figure 16. Tsunami inundation.

Figure 17. Damaged columns in the Nakasone Viaduct.

Figure 18. Damaged piers of the JR Rail Viaduct at the Tsuya River.

Figure 19. Ejected roller bearing and longitudinal movement at a pier of the Yuriage Bridge.

2.1.1 Overview of Exchanges in Topics Related to Seismic Effects at the Workshops

At the bridge engineering workshops, the participants presented their papers, discussed topics of mutual interest, and exchanged state-of-the-art technologies from both countries. These papers have also been published in the workshop proceedings and have provided valuable references for bridge professionals. According to the proceedings of past workshops, it is clear that seismic engineering has always been the most popular topic over the years. Figure 20 illustrates the number of papers that were presented on seismic topics at the individual workshops. On average, about 15 seismic papers were presented at each workshop. These research papers have covered a number of specific areas related to seismic engineering, as shown in Table 5.

Table 5. Seismic engineering-related areas and examples of issues discussed at the workshops.

Area of Discussion	Examples of Issue(s) Discussed
Seismic design	• Current seismic design specifications in the United States and Japan
Seismic retrofit	• The FHWA's Seismic Retrofitting Manual for Highway Structures • Retrofit techniques in California and Washington • Retrofit techniques in Japan
Tsunami	• Development of tsunami design criteria for Oregon coastal bridges • Method of estimating tsunami forces in Japan
Protective systems and bridge response	• Lock-up devices or shock transmission units in the United States • Testing and evaluation of a seismically isolated prestressed concrete I-girder bridge in Kentucky • Earthquake response characteristics of the Akashi-Strait Bridge in Japan
Strong-motion instrumentation and data acquisition and interpretation	• Fundamental concepts and research needs in the United States • Instrumentation of bridges in California
Seismic performance evaluation	• Effects of near-fault vertical accelerations on highway bridge columns in California • Seismic evaluation of the Gunkai-gawa Bridge in Japan
Earthquake engineering of cable-supported bridges	• Earthquake design of the East Kobe Bridge and the Honshu-Shikoku Bridge in Japan
Dynamic control and innovation in construction	• Base isolation for bridges in the United States • Precision control system in the Yokohama Bay Bridge in Japan
Earthquake case histories and reports	• Examination of the Great East Japan Earthquake, the Chile Earthquake, and the Hyogoken Nanbu Earthquake
Multiple hazards	• Use of seismic risk analysis of roadway systems in the United States • Development of reliability-based demand for bridge design under multi-hazard loads in the United States • Hydraulic model tests on the bridge structures damaged by tsunamis and tidal waves in Japan

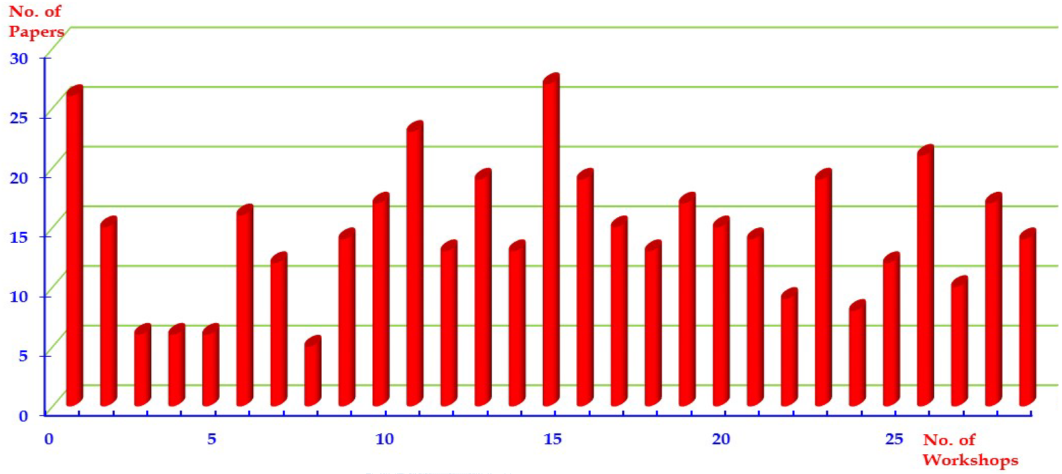

Figure 20. Number of papers on seismic topics presented at individual workshops.

2.1.2. Selected Seismicity Topics Discussed at the Workshops

Several seismicity topics that are of particular interest to workshop participants from both countries are selected for detailed discussion in this section. These topics include seismic design and seismic retrofit, which have been frequently discussed at past workshops. Also described herein are tsunamis, which have become a popular topic over the past three years after the Great East Japan Earthquake in 2011. The technical exchange in seismicity topics has enhanced understanding and assisted both countries to develop better practices to minimize losses due to earthquakes. It is apparent that seismic-related topics will continue to be exchanged in future workshops due to the complexity of the subjects.

Seismic design

Seismic design has been discussed and exchanged at most of the workshops. The discussions have included general design specifications, specific design of structural components, possible issues with current design and detailing requirements, and suggestions for future design and detailing enhancements. The current design specifications for highway bridges in the United States and Japan are further described in this section.

Bridge design specifications in the United States. Current seismic design in the United States is performed in accordance with either the *American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications* (6th Edition, with 2013 Interim Revisions) or the *AASHTO Guide Specifications for LRFD Seismic Bridge Design* (AASHTO Guide Specifications, 2nd Edition, with 2014 Interim Revisions) (*10, 11*). Both specifications include the design criteria of using a 1,000-year return period for a given level of earthquake, which represents not greater than a 7 percent probability of an earthquake occurring during a bridge design life of 75 years. The *AASHTO LRFD Bridge Design Specifications* address the force-based R-Factor method, while the AASHTO Guide Specifications focus on the ductility and displacement capacity of a structure, that is, a displacement-based approach. The AASHTO Guide Specifications were developed specifically for ordinary stringer bridges. These specifications account for the design factors that are calibrated to prevent collapse and reflect both the inherent reserve capacity to deform under imposed seismic loads and to accommodate relative displacements at the supports and articulated connections (*4*).

Bridge design specifications in Japan. Japan adopted performance-based design in the *Japanese Design Specifications for Highway Bridges* in 2002. The Japanese design specifications, recently revised in February 2012, require that bridges satisfy target seismic performances against Level 1 and Level 2 earthquake motions. Level 1 earthquake motion covers ground motion that is highly likely to occur during the service period of bridges; its target seismic performance is set to incur no damage. Level 2 earthquake motion is defined as ground motion with a high intensity with less probability to occur during the service period of a bridge. The target seismic performance for Level 2 earthquake motion is set to prevent fatal damage for bridges with standard importance and to limit damage for bridges with high importance. Compared to the 2002 edition, the 2012 revisions emphasize that bridges should be designed to account for ease of maintenance including periodic and emergency inspection, repair, and retrofit.

Seismic retrofit

Similar to seismic design, a tremendous amount of exchanges have focused on seismic retrofit at past workshops (*4*). A summary of selected findings reported by the workshop participants is given below:

- Studies presented by U.S. workshop participants:
  - The *Seismic Retrofitting Manual for Highway Structures* that was published by the FHWA was presented at the workshop in 2006. A performance-based retrofit philosophy was introduced similar to the performance-based design of new buildings and bridges. Performance criteria are provided for two earthquake ground motions with different return periods: 100 years and 1,000 years. Criteria are recommended according to bridge importance and anticipated service life, with more rigorous performance being required for important and relatively new bridges.
  - The Foresthill Bridge in California involved the use of large buckling restrained braces (BRBs), which solved a stability issue by using a passive device while allowing the service behavior of the bridge to remain unchanged.
  - A recent seismic retrofit program in the state of Washington involved over 900 bridges in high-risk zones. It incorporated a number of retrofit techniques for bridge superstructures including various combinations of restraining bars, hold downs, and reinforced concrete stops and thrust blocks. The retrofit techniques for bridge substructures included column jacketing using carbon fiber, Fiber Reinforced Polymers (FRPs), and welded steel. Also, friction pendulum-based isolation bearings were included to replace existing rocker bearings.

- Studies presented by Japanese workshop participants:
  - The Carbon Fiber Reinforced Polymer (CFRP) sheet jacketing method was successfully implemented to retrofit the main tower of the Tsurumi Tsubasa Bridge, a cable-stayed bridge, in Japan.

- The use of a combination of CFRP sheet jacketing and steel plate jacketing was studied for reinforced concrete bridge columns and was believed to provide a retrofit effect comparable to a typical steel jacketing.
- Introduction of anti-seismic devices in Honshu-Shikoku Bridges in Japan, including isolation bearings, was found to be effective.
- It was found to be effective to use low friction sliding bearing supports in continuous girder bridges. Use of these rubber-type buffers at the ends of girders has contributed to reducing the large displacement of the girder.

Tsunamis

Because a tsunami caused tremendous damage during the 2011 Great East Japan Earthquake, tsunamis have become a popular topic over the past three years. For example, damage analysis of bridges was discussed at the 27th workshop in 2011 (*4*). U.S. researchers presented the development of tsunami design criteria for Oregon coastal bridges. A model was developed for a potential tsunami wave characterized by height, direction, and speed.

It is worth pointing out that neither the *AASHTO LRFD Bridge Design Specifications* nor the *AASHTO Guide Specifications for LRFD Seismic Bridge Design*, the primary references for bridge designers in the United States, specify minimum requirements to resist tsunami loads (*4*). Discussions in recent workshops that contributed to formulate a number of research programs by state DOTs such as Caltrans and ODOT, as well as a pilot study conducted by the FHWA, filled this gap.

As a result of the outflow and excessive scour that occurred in bridges, numerous bridges were washed away by the tsunami during the 2011 Great East Japan Earthquake. The Japanese researchers have found that ratio β (that is, the ratio between girder resistance and wave lateral load) is a significant indicator to evaluate the extent of damage to bridge girders. Another model was created to develop uplift and horizontal forces on a bridge generated from a wave. As a result, an approximate method for estimating tsunami forces on bridge superstructures was developed.

2.2 Maintenance, Inspection, and Strengthening

Both the United States and Japan have been facing a common problem in bridge maintenance. Because a significant number of existing bridges have exceeded 50 years of service life, these bridges increasingly require extensive repair, rehabilitation, or even replacement. There is a need for both countries to have an appropriate preservation program to assess, evaluate, prioritize, and carry out actions to extend the service life of existing bridges. Figure 21 illustrates a chart that shows the relationships among various components relevant to a preservation program (*12*). Meanwhile, both countries are dealing with the urgency of advanced technologies on bridge inspection, assessment, evaluation, repair, and strengthening. Therefore, sharing and exchange of relevant knowledge and techniques at the workshops brings mutual benefits to both countries.

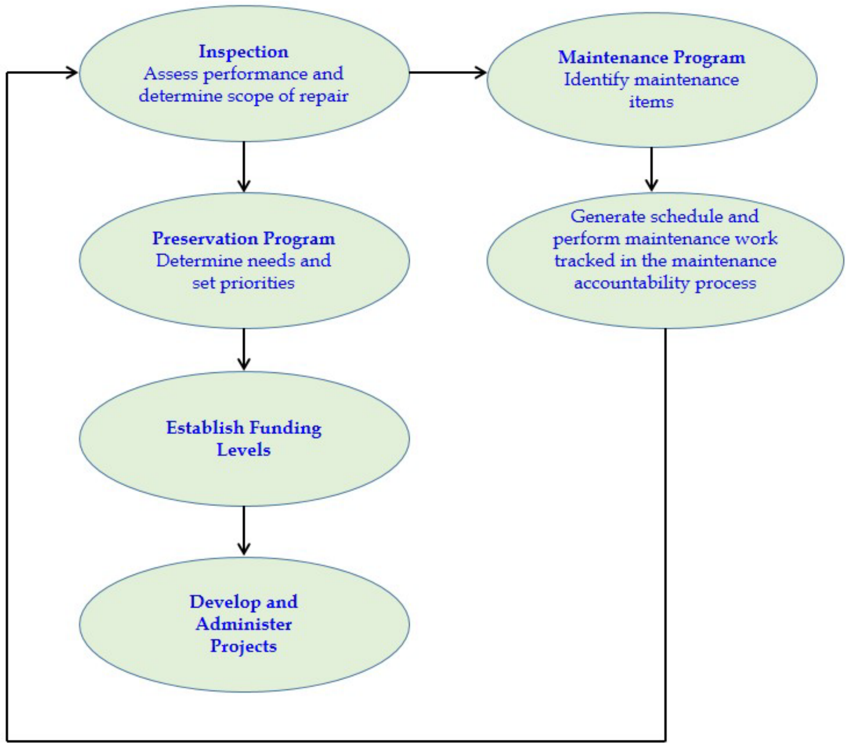

Figure 21. A flow chart of the preservation program.

2.2.1 Overview of Exchanges in Maintenance, Inspection, and Strengthening-Related Topics at the Workshops

Although discussions on maintenance, inspection, and strengthening-related topics were less frequent at the early workshops in the 1980s and 1990s, these exchanges increased significantly in the past 10 years. This is possibly because the preservation of existing bridges has become relatively urgent and needs newly-focused attention. Following the most popular topic, seismic effects, the second most discussed topic in all workshops is maintenance, inspection, and strengthening. On average, six papers were presented annually on this topic. Nearly 20 papers were presented at workshops in the early 2000s (Figure 22). The discussion has focused on a variety of areas as listed in Table 6. Periodic exchange of the technologies and resources has contributed to facilitate bridge condition assessment, inspection, evaluation, and preservation actions such as strengthening and rehabilitation, as well as health monitoring of the bridges.

Table 6. Maintenance, inspection, and strengthening-related areas and examples of issues discussed at the workshops.

Area of Discussion	Examples of Issue(s) Discussed
Maintenance, inspection, and strengthening	• A comprehensive bridge preservation program to extend bridge service life in the United States • Concrete bridge deck condition assessment using the Robotic System RABIT in the United States • Bridge inspection standards in both countries • Non-destructive bridge deck assessment using Image Processing and Infrared Thermography in both countries • Element level inspection results and accuracy in probabilistic structural condition forecast for bridges in Japan • New methods for inspection and evaluation of steel gusset plate connections in Japan • Study of repair methods using CFRP for corroded steel girder ends in Japan
Evaluation, rating, and management	• Reliability-based evaluation of bridge live load carrying capacity in the United States • Management strategies for the U.S. highway bridge network in the United States • Evaluation of prestressed concrete structures using vibration measurement in Japan • Maintenance management of the Honshu-Shikoku Bridge Expressway in Japan
Fatigue and corrosion	• Research on corrosion inhibitors for steel in concrete in Florida • Corrosion costs in the United States • Fatigue and corrosion in concrete decks with asphalt surfacing in Japan • Study of fatigue cracks in a steel deck plate girder bridge in Japan
Structural monitoring and diagnostics	• Instrumentation and monitoring of the I-35W St. Anthony Falls Bridge in Minnesota • Non-destructive monitoring of the main cables of the Manhattan Bridge, a suspension bridge, in New York • Structural monitoring using piezoelectric film in Japan

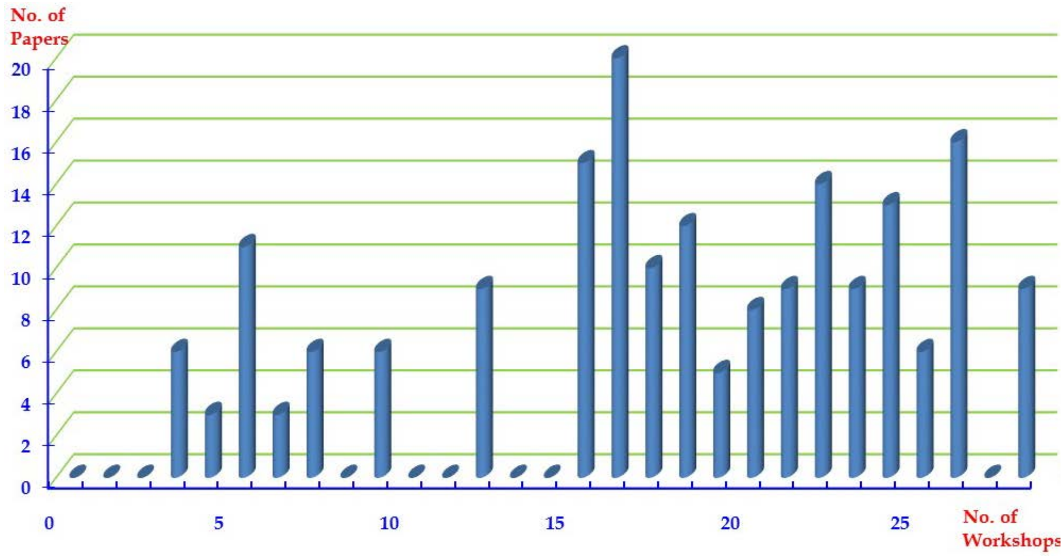

Figure 22. Number of papers on maintenance, inspection, and strengthening presented at individual workshops.

2.2.2 Selected Topics in Maintenance, Inspection, and Strengthening Discussed at the Workshops

By sharing state-of-the-art technologies on maintenance, inspection, and strengthening of bridges, it is clearly beneficial to both the United States and Japan in improving current practices. Frequently discussed topics at past workshops such as inspection and condition assessment are described in detail in this section. The inspection approaches in both countries are presented and compared. Bridge condition assessment has also been of interest to workshop participants. The condition assessment involves various non-destructive evaluation (NDE) technologies that have been recently developed and implemented. As existing bridge structures continue to age, discussions on bridge maintenance, inspection, and strengthening, as well as bridge safety, will continue in future workshops.

Inspection

In the United States, bridge inspectors perform inspection in accordance with the National Bridge Inspection Standards. Element-level inspection protocols and visual and non-destructive techniques are used to inspect and assess the condition of a bridge at regular intervals varying from two to five years. These intervals are dependent on the minimum federal requirements and a risk assessment of an individual bridge that considers bridge type, actual condition, structural redundancy, and the inspector's professional judgment. There are three inspection categories: routine inspection, fracture critical inspection, and underwater inspection. Federal regulations require that routine inspections be performed every two to four years, fracture critical inspections every two years, and underwater inspections every five years (*4*). Each bridge is divided into major components including girders, deck, substructure, etc. The inspector gives a rating of 0 to 9 for each component, which is based on the severity of damage and urgency of action. After each inspection, the inspector submits the bridge inspection report to the bridge owners. The information in the report is added to a national database that includes the historical records of individual bridges.

In Japan, element-level inspection standards, which are similar to the practices in the United States, are also implemented. However, Japanese inspectors define the "element" differently from the U.S. practice. Their definition of element is closely related to the finite element analysis that will be performed for the bridge. Also, they include 13 categories for various levels of defects in each element instead of 10 categories in the United States. Their data recording philosophies, however, are comparable to those used in the United States.

Condition assessment

In a traditional sense, bridge conditions have been primarily assessed by visual inspection. Visual inspection relies extensively on the bridge inspector's subjective judgment, which depends on experience, knowledge, and varying field conditions. As technology progresses, advanced inspection methods allow for more accurate assessment of bridge conditions without solely depending on human inspectors.

In the United States, one of the advanced systems implemented is a robotic system, the RABIT (Robotics Assisted Bridge Inspection Tool), for assessment of concrete bridge decks. It was developed as a result of the FHWA's Long-Term Bridge Performance (LTBP) program (*4*). This system involves multiple NDE technologies that characterized the three most common deterioration types: corrosion of reinforcing bars, delamination, and concrete degradation. The RABIT uses four NDE technologies (electrical resistivity, impact echo, ground-penetrating radar, and ultrasonic surface waves) and advanced vision to complement traditional visual inspection. Figure 23 shows a photo of the RABIT including NDE and navigation components.

Another innovative NDE assessment technology involves the use of infrared thermography and digital concrete surface imaging. It was implemented to assess the condition of the deck slab for a bridge in Florida. Figure 24 shows the scanned bridge in downtown Orlando. Figure 25 presents the real-time IR thermal image, while Figure 26 shows the output of the assessment including areas marked in critical condition.

In Japan, a variety of state-of-the-art sensing and NDE inspection and evaluation technologies have been developed. Vibration measurement was conducted to assess the extent of damages in prestressed concrete bridges. It was found that the vibration measurement was capable of detecting deterioration when prestressed concrete bridges suffered severe damage. The vibration tests included the vehicle impulse load method (Figure 27), the falling weight method, and the ambient vibration method. The detection of damage was achieved by comparing the vibration characteristics in a sound state and those in a current state.

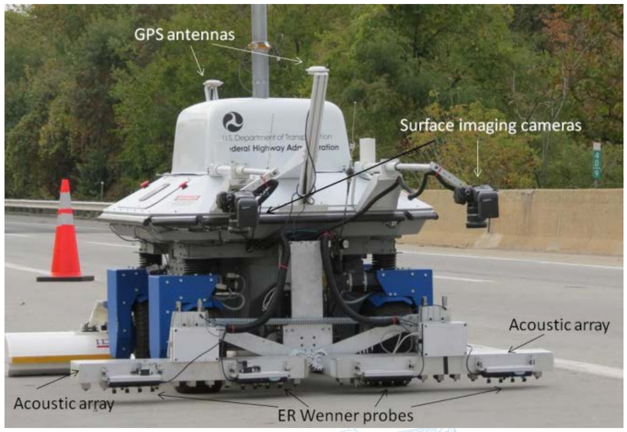

Figure 23. Front end of the RABIT with NDE and navigation components.

Figure 24. A bridge in Orlando assessed by IR technology.

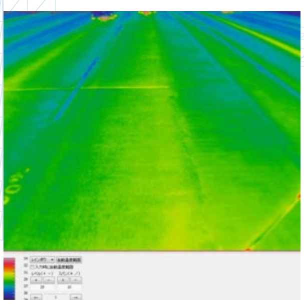

Figure 25. Real-time IR image.

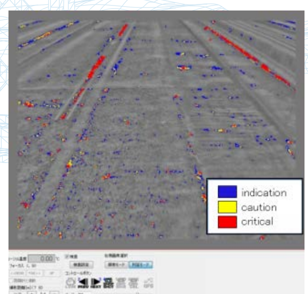

Figure 26. IR output.

Figure 27. Vibration test using the vehicle falling method.

2.3 Design and Analysis

To ensure bridge safety, the United States has followed the rigorous bridge design provisions specified in the *AASHTO LRFD Bridge Design Specifications*. The *AASHTO LRFD Bridge Design Specifications* were adopted as a 1994 document as an equal alternative to the previously used *AASHTO Standard Bridge Design Specifications*. The FHWA mandated that all federally funded highway bridge projects be designed in accordance with the *LRFD Bridge Design Specifications* beginning in October 2007. The *LRFD Bridge Design Specifications* have incorporated a new design methodology as well as reliability-based and probabilistic-based load and resistance factor design, with numerous state-of-the-art advances in the calculations of loads and resistance. The current *LRFD Bridge Design Specifications* provide provisions for the analysis and design of the superstructure, including reinforced concrete, prestressed concrete, and steel structures, and the substructure including abutment, pier, and foundation.

Discussions on the *AASHTO LRFD Bridge Design Specifications* at past workshops have apparently influenced the Japanese participants. They proposed and assessed a calibration method of load and resistance factors recently, in which the load factors were set to match the same level of reliability as designs based on the current specifications. As a result, there is a trend of introducing the load and resistance factor design method in Japanese design specifications, which is the same design philosophy underpinning the *AASHTO LRFD Bridge Design Specifications*. Load and resistance factor design enables one to account for the degree of reliability of materials and the load factors corresponding to various levels of design, which allows for a more rational design. This design method is particularly reasonable considering the rapid development of high performance materials.

The use of high performance materials has allowed for increased structural capacity. For example, precast pretensioned concrete I-girders have been commonly used in highway bridges in the United States. Due to the use of high performance concrete (HPC) and enhanced girder handling and shipping capacity, over 200-foot-long precast I-girders have been successfully used for bridges in the state of Washington. Similar to the use of HPC, the FHWA initiated an effort with the American Iron and Steel Institute and the U.S. Navy to develop new high performance steel (HPS) for bridges in the early 1990s. Grade 70W (weathering) and Grade 100W were identified to meet the definition of HPS, which can develop higher strength, improved weldability, and high toughness to enhance the overall quality and fabrication of steel.

Japan has adopted the use of HPS in its bridge design specifications since 1996. The use of HPS has contributed to the wide use of steel bridge fabrication and construction. It has allowed for efficient design of steel bridges, increased structural performance and durability, and decreased initial construction costs. In addition, Japan has implemented weathering steel in bridges, which has the benefit of eliminating painting, and therefore significantly reduces the cost.

2.3.1 Overview of Exchanges in Design and Analysis-Related Topics at the Workshops

Due to recent advances in new materials, design theories, and analysis tools, bridge design and analysis practices have continued to be upgraded and refined. It has been advantageous to hold annual workshops where participants from both countries can discuss and exchange their experiences with the same topic and learn from each other. Sharing the technologies on bridge design and analysis has been frequent at past workshops. Figure 28 illustrates the number of published papers on the design and analysis at past workshops. On average, six papers were presented annually in design and analysis, and over 20 papers were presented at the 14th workshop in 1998. Areas of discussion are summarized in Table 7.

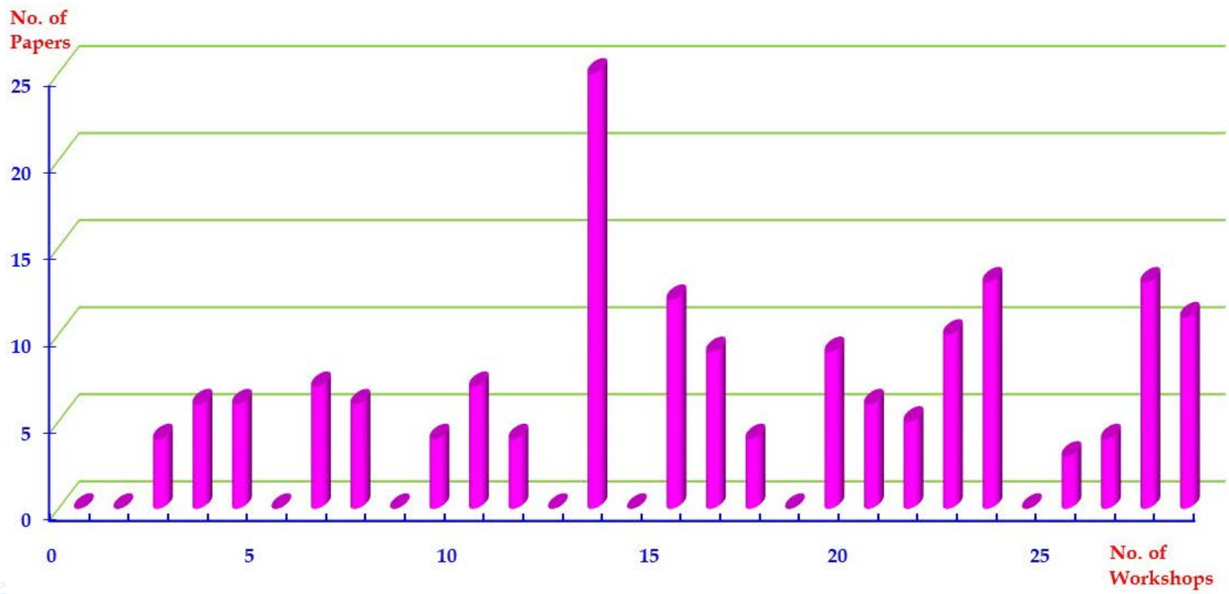

Figure 28. Number of papers on design and analysis presented at individual workshops.

Table 7. Design and analysis-related areas and examples of issues discussed at the workshops.

Area of Discussion	Examples of Issue(s) Discussed
Loads	• NCHRP research on recalibration of the LRFR load factors in the AASHTO Manual for Bridge Evaluation in the United States • Review of permit loads in Oregon • Stochastic simulation of design load combinations for highway bridges in Japan • Calibration of load factors for highway bridge design in Japan
Design and behavior of concrete bridges	• Design-build of the I-35W Bridge replacement in Minnesota • Study of precast composite slab span system in the United States • Pile to slab bridge connections in the United States • Effectiveness of cohesion on horizontal shear transfer for composite prestressed concrete girders in Japan
Design and behavior of steel bridges	• Development of high performance steel in the United States • Flexural strength and ductility of HPS-100W bridge girders in the United States • High performance steel bridge research in the United States • Application of high performance steel in Japan • Analysis of the influence of breaking members of steel through truss bridges in Japan
Jointless bridges	• Integral abutment for jointless bridges in the United States • Design and construction guidelines for integral abutment bridges for Japanese highways • Jointless prestressed concrete viaduct using engineering cementitious composite in Japan
General design and analysis issues	• The structural design of pile foundations based on LRFD for Japanese highways • Design of a new steel pipe integrated pier with shear link in Japan

2.3.2 Selected Topics in Design and Analysis Discussed at the Workshops

Workshop participants have actively discussed the state-of-the-art practices in bridge design and analysis in the United States and Japan. The discussions have focused on the current design methods; new materials such as HPC, HPS, FRP, and CFRP; testing programs; and research development. Of the topics discussed, subjects such as the design and behavior of concrete and steel bridges were frequently mentioned and exchanged. At one workshop, U.S. participants presented the newly built segmental bridge, the I-35W Bridge in Minnesota, as a case study in bridge design. Japanese participants discussed their research on interface shear resistance in prestressed concrete bridges. This section summarizes the discussions presented by workshop participants in the design of concrete and steel bridges. Additionally, the recent development and implementation of HPS and weathering steel for steel bridges in the United States and Japan is described.

Design of concrete bridges

There have been extensive discussions on the design and behavior of concrete bridges at past workshops. Topics of exchange have included case studies of specific projects, design of particular members such as columns, evaluation of connection details, and research findings on various structural systems. For example, the U.S. participants presented a case study of the I-35W Bridge in Minnesota (Figure 29). This bridge consists of separate crossings for both northbound and southbound traffic. Each structure has four spans with a maximum span of 504 ft. and involves the use of dual concrete box girders. This segmental bridge includes precast segments varying from 13.5 ft. to 16.5 ft. in length and 11 ft. to 25 ft. in depth. This bridge uses large disc bearings that are pinned against translation in all directions. It was designed for a 100-year service life.

Figure 29. I-35W Bridge in Minnesota.

The Japanese participants have also discussed similar topics and presented research findings on the design of prestressed concrete bridges. In their research, they examined the effectiveness of cohesion on horizontal shear transfer for composite prestressed concrete girders. The existing provisions in the *AASHTO LRFD Bridge Design Specifications* were included as a primary reference in their research study. The Japanese researchers performed interface shear tests of three T-section girders. Based on the testing results, an estimation of interface shear resistance was suggested accounting for various roughened surface conditions.

Design of steel bridges

In the United States, it is a common practice to use American Society for Testing and Materials (ASTM) A709 Grade 50 for all structural steel in bridge girders, including flanges, webs, bearing stiffeners, intermediate stiffeners, cross frames, diaphragms, and splice plates (*4,13*). A hybrid section consisting of flanges with a higher yield strength than that of the web may be adopted to save materials, which becomes more desirable due to the use of HPS. Grade 70 steel can be used at the top and bottom flanges in negative moment regions and the bottom flange in positive moment regions. Grade 50 steel can be included for all webs, which provides the most efficient hybrid girder. The use of HPS and weathering steel is also encouraged, except in conditions where the atmosphere has concentrated corrosive industrial or chemical fumes and in locations subject to high rainfall and severe humidity.

In Japan, similar to practices in the United States, HPS has been used for highway bridges for nearly 20 years. Weathering steel has also been used to reduce the initial cost of steel bridges. High cold formability weathering steel, weathering longitudinally-profiled steel plates, seaside weathering steel, and new techniques such as treatment for promoting protective rust formation have been implemented to improve the reliability of steel bridges.

There have been improvements in design and analysis that were initiated by unique events. For example, the collapse of the I-35W truss bridge in Minnesota in 2007 resulted in extensive studies on the performance, analysis, and rating of gusset plates in the United States. U.S. participants presented their research and analysis related to the I-35W bridge at the workshop. The collective findings were later adopted in the *AASHTO LRFD Bridge Design Specifications*. At the workshops, Japanese participants also discussed their practices and research findings on the gusset plates, including (1) the method of inspecting and evaluating the gusset plate connections, and (2) the compressive loading test of corroded gusset plate connections.

2.4 Wind

Bridge structures are designed to resist a variety of loads including lateral loads such as wind and seismic loads, and vertical loads such as dead and live loads. Loading analysis typically accounts for a series of load combinations corresponding to different states of load conditions. Although the design for wind loads is generally not critical for short- to medium-span bridges, as the dead and live loads are predominant, it is extremely critical for long-span bridges such as cable-stayed bridges and suspension bridges. As a result, the wind design for long-span bridges was one of the focused topics at the workshops.

Because long-span bridges have low natural frequencies and small structural damping, they are highly sensitive to wind effects (*4*). Long-span bridges may experience vortex-induced vibration, turbulence-induced buffeting, and motion-induced flutter instability. The world's longest suspension bridge, the Akashi-Kaikyo Bridge (known as the Pearl Bridge), with a central span of 6,532 ft. in Japan, and the world's longest cable-stayed bridge, the Russky Bridge, with a central span of 3,622 ft. in Russia, are bridges that demonstrate the significance of aerodynamic design in long-span construction. It is crucial to have an advanced understanding of wind-bridge interaction to satisfy the increasing safety and economic needs for long-span bridges.

2.4.1 Overview of Exchanges in Wind-Related Topics at the Workshops

The importance of wind design for long-span bridges has resulted in numerous discussions, particularly at the early workshops (i.e., from the 2nd to 17th workshops) held between 1985 and 1999 (Figure 30). U.S. participants shared their experiences in aerodynamics stability and simulation techniques through the studies of a number of cable-stayed and suspension bridges. Table 8 presents a detailed list of wind-related topics that were exchanged at past workshops. It is worth mentioning that a majority of the research papers presented on wind design came from Japanese workshop participants. It is speculated that there has been declining interest in this topic from U.S. researchers and engineers in the past 15 years, which caused the discussions on wind design to gradually phase out.

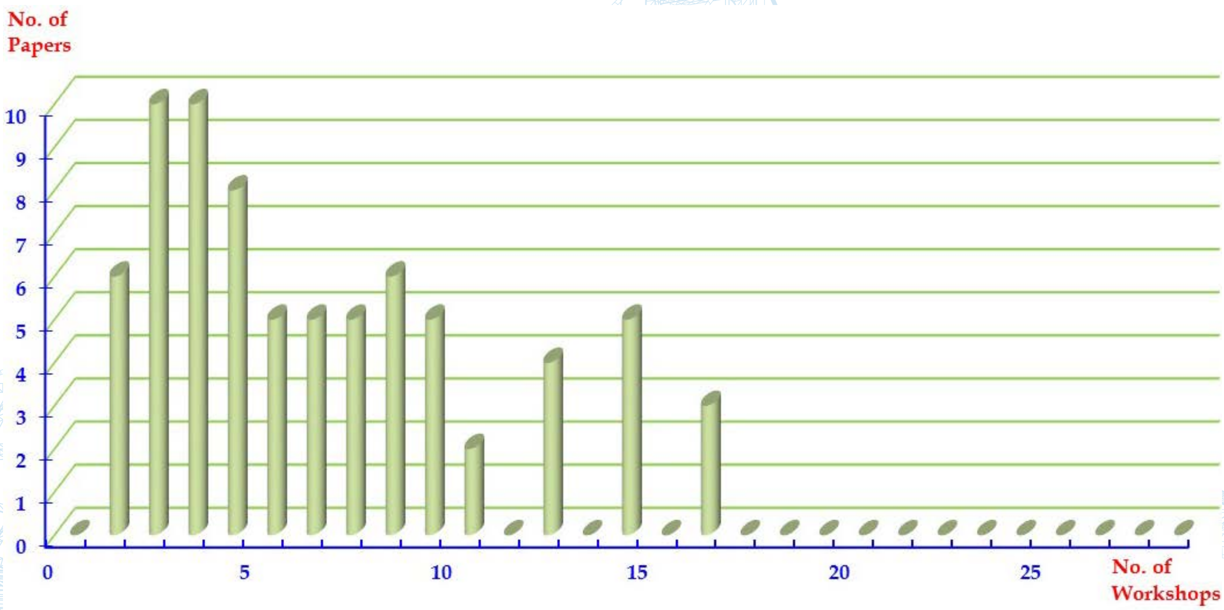

Figure 30. Number of papers on wind presented at individual workshops.

Table 8. Wind-related areas and examples of issues discussed at the workshops.

Area of Discussion	Examples of Issue(s) Discussed
Wind effects and wind-resistant design	• Role of flutter derivatives in wind effects on cable-stayed bridges in the United States • Wind characteristic map of Osaka City for bridge design in Japan • Analytical study on flutter of suspension bridge in Japan
Aeroelasticity and aerodynamics of bridges	• Simulation techniques for bridge aerodynamics investigation at the Turner-Fairbank Highway Research Center in the United States • Structural modifications for enhanced aerodynamic behavior of a suspension bridge in the United States • Aerodynamics stability of the Central Nagoya Port Bridge in Japan • Aerodynamics stability of the Nakajima Bridge in Japan • Aerodynamics stability of the Trans-Tokyo-Bay Highway Bridge in Japan
Experimental study	• Experimental study on aerodynamics stability of suspension bridges with open grating decks in Japan • An experimental study on aerodynamics sound generated from handrails of flat plate cascades in Japan
Vibration	• Preventing wind-induced vibration of the Kansai International Airport Access Bridge in Japan • Wind tunnel test and vibration control damping for the tower erection stage of the Nagoya Port Central Bridge in Japan

2.4.2 Selected Topics in Wind Discussed at the Workshops

Long-span bridges such as cable-stayed and suspension bridges require meticulous attention to wind design and analysis. Severe structural failures have occurred due to a lack in understanding of wind effects. Researchers and engineers have accumulated their understanding and knowledge through laboratory study and simulation, wind tunnel tests, practical bridge design and construction, and lessons learned from failures.

At workshops, sharing of state-of-the-art technologies on wind design is indispensable in order to facilitate a solid understanding of the critical design issues. This section focuses on frequently exchanged topics at the workshops such as wind-resistant design and aerodynamics. Wind-resistant design is improved by listing the design criteria of the Akashi-Kaikyo Bridge in Japan, the longest suspension bridge in the world. Discussions on how to improve or secure aerodynamics stability are also included.

Wind-resistant design

Workshop participants have discussed the wind-resistant design of long-span bridges such as the Akashi-Kaikyo Bridge in Japan, which has extremely flexible features (*4*). Wind-resistant design typically consists of two stages. In the first stage, the drag component of the aerodynamic force that affects the determination of the sectional dimensions of structural members is replaced with static load accounting for the gust response in the drag. Based on this static load, stress calculations are performed to determine the section of the member.

In the second stage, the buckling of the structure and the harmful vibrations are checked by dynamic analysis, wind tunnel tests, and other tests. When the Akashi-Kaikyo Bridge was designed, additional design criteria were included due to its extremely long span. Horizontal deflection components, as well as vertical and torsional components to gust response, were considered in the design. Additionally, both smooth wind and turbulent wind were included in the tunnel test.

Aerodynamics

Ever since the Tacoma Bridge disaster occurred in 1940, designers of long-span bridges have become aware of the great importance of aerodynamic stability of these structures. Extensive studies have been performed on aerodynamic stability with a number of significant bridges including the Deer Isle-Sedgwick Bridge in the United States and the Central Nagoya Port Bridge, Nakajima Bridge, and Trans-Tokyo-Bay Highway Bridge in Japan.

It is now known that the primary approaches to improve or secure aerodynamic stability are to increase the rigidity of the structure, increase the damping in the structure, or modify the shape of the structure. Any method of increasing rigidity is generally effective in augmenting the structural damping. An increase in rigidity and damping to resist vertical and torsional instabilities can be achieved through use of deeper stiffening girders or trusses, longitudinal cable stay systems, continuous construction, or unloaded back stays. Resistance to torsional instabilities can be enhanced by using transverse diagonal stay systems, installing top and bottom lateral bracing systems, increasing the torsional stiffness of support towers, and raising the location of suspender connections relative to the center of gravity of the section. In addition, wind tunnel tests are necessary to investigate the effects of turbulence.

2.5 General Topics, Construction, and Materials

Previous U.S.-Japan Bridge Engineering Workshops have covered nearly all areas of bridge engineering. In addition to the topics discussed in previous sections, other subjects such as general topics, construction, and materials have also been covered at past workshops. The general topics included frequent updates on the research programs initiated by national governmental agencies such as the FHWA and the Transportation Research Board's National Cooperative Highway Research Program (NCHRP) in the United States, as well as the PWRI in Japan. Participants from U.S. state DOTs have also presented and discussed their research programs at these workshops. This type of prompt briefing has been beneficial for workshop attendees to become aware of the latest research developments.

The practices in the bridge industry are significantly affected by advancement of the construction equipment and fabrication technologies. A recently popular topic, Accelerated Bridge Construction (ABC), is a good example demonstrating the immediate impact on the construction industry due to innovation in implementation of prefabricated members. This section begins with an overview of the exchanges in general topics, construction and materials-related topics, and then discusses in detail ABC as a selected topic.

2.5.1 Overview of Exchanges in General Topics, Construction, and Materials-Related Topics at the Workshops

At some workshops, participants conducted extensive exchanges in general topics, construction and materials. Table 9 summarizes these specific areas that were discussed and gives examples of issues that were addressed. Some subjects were discussed extensively at individual workshops. For example, 13 papers were presented on geotechnical engineering at the 22th workshop in 2006. Current practices and challenges relevant to geotechnical engineering were discussed, which was advantageous to resolve issues common to both countries. Such sharing of knowledge always facilitates further improvements and enhancements of bridge technologies.

Table 9. Specific areas related to general topics, construction, and materials and examples of issues discussed at the workshops.

Area of Discussion	Examples of Issue(s) Discussed
General issues	• Overview of the FHWA bridge engineering research and technology • Resilient bridge design in the United States • Caltrans' next generation bridge • Priority research projects of the PWRI • Study on grout conditions of existing prestressed concrete bridges in Japan
Bearings	• Optimal design strategies for base-isolated bridges in the United States • Bridge base isolation program in Caltrans
Substructure	• Evaluation and upgrading of multi-column bridges in the United States • Applicability of the H-jointed steel pipe sheet pile as a bridge pier foundation in Japan • Effects of shear span ratio on the fracture of deep beams in Japan
Accelerated Bridge Construction (ABC)	• ABC in Washington, Texas, and California • Performance of ABC connections in bridges subject to extreme events in the United States • Overview of the development process and effects of the UFO (Uni-Fly-Over) method in Japan • Accelerated construction of the viaducts on the Second Keihan Expressway in Japan
Advanced materials	• Use of ultra-high performance concrete for bridge design in the United States • Development, testing, and deployment of FRP materials in Japan
Composite materials	• Thin CFRP grids for bridge deck reinforcement in the United States • Experiences in the upgrade and new construction of bridges with composite materials in the United States • Experiments on the bolted joint strength of pultruded GFRP laminates in Japan
Geotechnical engineering	• Implementation of micropiles by the FHWA • Performance-based liquefaction potential in Japan

2.5.2 Selected Topics in General Topics, Construction, and Materials Discussed at the Workshops

Of all general topics, construction, and materials discussed at the workshops, new construction methods, e.g., ABC, were some of the hottest topics of interest to participants from both countries. Construction practices in implementing ABC demonstrate that this method is cost-effective and results in less disruption to traffic. This section provides a more detailed description of what participants have discussed at the workshops.

Accelerated Bridge Construction (ABC)

ABC has become very popular in the United States in recent years. The primary reasons to use ABC are to reduce the onsite construction time, minimize the traffic impacts, and enhance the safety of the traveling public and contractor personnel. Under the FHWA's leadership in the ABC research program, innovation in development and implementation of prefabricated bridge elements and systems (PBES) has been encouraged. By implementing structural components that are built offsite or near the bridge site, PBES reduces the onsite construction time and mobility impact time incurred by conventional construction methods. PBES involves the use of high-performance materials and "Fast Track Contracting" methods. Specifically, it includes the prefabricated members such as deck panels, beams, barriers, abutment and wall elements, piers, and columns. PBES also includes Prefabricated Systems, which consist of an entire superstructure, an entire superstructure and substructure, or even a total bridge that is procured in a modular manner. ABC may involve the use of a self-propelled modular transporter (SPMT). SPMT is a high capacity transport trailer that can lift and move prefabricated elements with a high degree of precision and maneuverability. The use of SPMT may allow for completion of a bridge overnight or within a weekend.

Due to the importance of the connections for prefabricated elements subject to extreme event loading, a tremendous amount of discussions have taken place at workshops on the connection details. In particular, the performance, standardization, monitoring, and maintenance of ABC connections subject to multi-hazard loading have been extensively exchanged. ABC has been successfully implemented in a number of states in the United States including Washington, Texas, and Florida. Figures 31 and 32 illustrate the installation of a precast pier cap for bridges in Washington and Texas, respectively. Figure 33 shows the erection of full-depth precast panels in the Live Oak Creek Bridge in Texas.

The Japanese participants have also addressed the benefits of ABC due to reduced construction time and minimized disturbance to traffic. They have used precast components in bridges including precast beams and precast deck panels (Figures 34 and 35).

Figure 31. Installation of precast bent cap in Washington.

Figure 32. Installation of precast cap in the Lake Belton Bridge.

Figure 33. Erection of full-depth precast panels in the Live Oak Creek Bridge.

Figure 34. Erection of a precast U-girder.

Figure 35. Installation of precast panels.

Chapter 3. Accomplishments and Benefits

In this chapter, the major accomplishments and benefits realized from the U.S.-Japan Bridge Engineering Workshops are presented. It is worth pointing out that the first and most celebrated accomplishment is that the workshop has been successfully held annually over a period of 30 years. On average, more than 50 participants attended each of the workshops. This participation demonstrates the unwavering support, as well as the continued interest, of the engineering communities in both the United States and Japan.

The chapter is organized in two sections. Section 3.1 summarizes the accomplishments of the workshops, which range from technology exchanges to research on how to recover from disasters. Section 3.2 presents a detailed discussion of benefits realized from the workshops.

3.1 Overview of Accomplishments

In addition to promoting the continuing cooperation and collaboration between the United States and Japan, the U.S.-Japan Bridge Engineering Workshops have made other significant contributions to the bridge engineering discipline. The major accomplishments of the workshops include technology exchanges, cooperative research projects, collaboration, networking, personnel exchanges and training, reconnaissance efforts, and management of extreme events. All of these accomplishments have become driving forces for technology advancement and future cooperation between these two countries in bridge engineering. Below is a discussion of each of the major accomplishments.

Technology exchanges and advancement. As mentioned in Chapter 2, a tremendous amount of state-of-the-art bridge technologies have been exchanged at past workshops. As a result, both countries have learned about current practices from each other. Comparative research projects have been established in order to promote the advancement of the state-of-the-art practices in the United States and Japan.

Collaboration. The collaboration between the United States and Japan in the workshops has facilitated coordination efforts of governments, academia, and industry to improve the understanding of specialty areas such as earthquake protective systems and seismic retrofitting techniques.

Reconnaissance. The United States and Japan have made tremendous joint reconnaissance efforts on a number of significant earthquakes including the Northridge Earthquake (California) in 1994, the Hyogoken Nanbu (Kobe) Earthquake in 1995, the Maule Earthquake (Chile) in 2010, and the Great East Japan (Tohoku) Earthquake in 2011. Similar reconnaissance efforts have also been made with other devastating events such as hurricanes. These reconnaissance efforts have subsequently led to improved bridge design specifications and reduced hazards to human life and property.

Networking. The collaboration in the area of bridge engineering between these two countries, to a great extent, has been a result of the networking that has been established during the past workshops. The workshops have provided a superior platform for attendees to form a professional network and gain familiarity and trust with each other. This networking has gradually expanded as more workshops have been held and more attendees have been involved.

Personnel exchanges and training. The personnel exchange program, which allows persons from one country to stay in the partner country for a period varying from one week to one year, has undoubtedly strengthened the personal and professional ties among the participating individuals, which has benefited both countries.

Research programs. There appears to be a link between the extensive networking and the joint reconnaissance efforts of the effects of devastating events such as earthquakes and tsunamis. Research programs have been recently developed in both countries to further investigate these events. The research findings have been successfully incorporated in relevant codes and specifications to improve design practices. In addition, extensive exchanges on how to handle these devastating events has allowed both countries to improve their abilities to withstand, respond to, and recover from these disasters.

3.2 Specific Benefits Experienced from the Workshops

The workshops have produced a number of benefits that have impacted both countries in bridge engineering and have fostered a deep cooperation and collaboration between the two countries. These benefits, categorized into seven areas, are listed as follows:

- Sharing and exchange of technologies for mutual benefits.
- Cooperative research programs.
- Collaboration.
- Professional networking.
- Personnel exchanges and training.
- Reconnaissance.
- Response and recovery from devastating events.

3.2.1 Sharing and Exchange of Technologies

The workshops have become a well-established channel for the exchange and communications of technologies. The attendees have taken the opportunity to present state-of-the-art technologies, to interact with other workshop participants, and to learn from each other. Sharing knowledge is extremely important and necessary for the bridge engineering profession and for society as a whole. For example, earthquake engineering is a challenging endeavor in which it is nearly impossible to make quick progress (*5*). This is because damaging earthquakes are rare and learning from earthquakes is time-consuming. But society demands quick answers, and engineers are required to make decisions based on limited facts, limited time, and evolving science. These decisions cover a wide area, from development of codes and specifications to allow for proper design and retrofit practices, to establishment of regulations and guidance, to repair damaged structures effectively and promptly after extreme events occur. The quality of these decisions affects the safety of millions of people living in seismically active areas.

One of the most effective ways to build upon relevant knowledge, from which proper decisions can be made, is to share experiences among countries. The United States and Japan are the world leaders in seismic resistant design. They are recognized as having high standards of engineering and placing a very high value on human life. The opportunity for an annual exchange of such experiences at the U.S.-Japan bridge workshops has therefore been extremely valuable, not just for the United States and Japan, but for the entire world. This serious leadership responsibility has caused seismic engineering to be one of the primary topics for discussion at the past 29 workshops.

U.S. technologies shared with Japan. The bridge workshops have brought benefits to Japan in terms of gaining a better understanding of bridge technologies implemented in the United States. Through the exchanges at the workshops, Japanese engineers are exposed to subjects such as revisions of codes and standards, development of new technologies, research interests, governmental policies, and investigation of disasters. The following are examples of technologies that Japan has adopted from the workshops (*9*):

- In terms of new concepts for bridge design, the United States has shared its knowledge of ductile structure design. Japan has also become aware of new design concepts being utilized in the new San Francisco Bay Bridge.
- Japan has learned several concepts for ABC from participating U.S. bridge engineers.
- Information on the monitoring sensors used in the I-35W Bridge reconstruction project in Minneapolis, Minnesota has been helpful to Japanese participants.
- Japanese participants have benefited from the exchange of information by U.S. participants relative to new seismic retrofits such as steel jacketing methods for concrete columns and the gap concept at the bottoms of columns. Seismic retrofit projects for long-span bridges in California have also been beneficial to Japan.
- Recent publications such as the *AASHTO LRFD Bridge Design Specifications* and the Caltrans Bridge Design Practice Manual have been valuable references to Japan.
- Japan has benefited from new concepts in LRFD of new bridges and Load and Resistance Factor Rating (LRFR) of existing bridges, including the modified compression field theory of shear resistance and the shear-friction theory in areas subject to concentrated loads.

Japanese technologies shared with the U.S. Through the exchanges at the workshops, U.S. participants have gained a better understanding of the activities performed by Japanese engineers in the following areas (*6*):

- A number of technologies have been developed, tested, and proven in Japan regarding bridge seismic retrofitting measures, such as restrainers, steel or concrete jackets and FRP jackets for shear strengthening and ductility enhancement of columns. As a result of the U.S.-Japan collaboration, the innovations have been implemented in high seismicity areas in the United States such as California, Washington, and Oregon. Additional applications include the introduction of isolation bearings, such as High Damping Rubber Bearing and Friction Pendulum Isolators, in west coast states (i.e., California, Washington, and Oregon) as well as in the central United States (i.e., Tennessee and Missouri).

- Japanese technologies and methods of seismic design and detailing in ABC have been shared with the U.S. and have been applied in the development of seismic design guidelines in prefabricated bridge columns and piers.
- Recovery technology and emergency planning lessons learned from Japanese experience in large earthquakes and tsunamis have helped the United States improve the technologies and methodologies in handling extreme events.
- Weathering steel with special treatments has been used in the northern part of Japan (e.g., Hokkaido). After it was introduced and discussed at the bridge workshops, the eastern seaboard states in the United States explored the use of more weathering steel in bridge superstructures.

3.2.2 Cooperative Research Programs

As a result of frequent technology exchanges, a number of cooperative research programs between the two countries have been established. These cooperative research programs generate valuable new research based on the combined expertise from the two countries. Some of these programs are listed below:

- Development of Draft Guidelines for Experimental Verification of Seismic Performance of Bridges including the quasi-static cyclic loading tests and shake table tests for bridge columns.
- A comparative study of the U.S.-Japan seismic design of highway bridges, seismic control systems, and seismic testing protocols.
- U.S.-Japan joint reconnaissance of damaged bridges due to earthquakes, including the bridges damaged by the Northridge Earthquake (1994), the Hyogo-ken Nambu Earthquake (1995), the Chile Earthquake (2010), and the Tohoku Earthquake (2011).
- A collaborative research program to improve the numerical modeling of tsunami effects, develop design procedures, and validate the procedures using wave basin experiments.

These cooperative research programs have resulted in jointly published journal papers and reports. They have been effective for both countries in the development of design guides and code provisions. They also have advanced various construction methods and maintenance technologies for bridges (*9*).

3.2.3 Specialty Area Collaboration

In addition to the cooperative research programs, a number of collaborative workshops were held in the 1990s that focused on specialty areas such as earthquake protective systems and seismic retrofitting techniques. A total of seven workshops were held from 1990 to 1996 as listed below (*8*):

Four U.S.-Japan workshops on Earthquake Protective Systems for Bridges:

1. Buffalo, NY, 1992
2. Tsukuba, Japan, 1992
3. Buffalo, NY, 1994
4. Osaka, Japan, 1996

Three U.S.-Japan workshops on Seismic Retrofit of Bridges:

5. Tsukuba, Japan, 1990
6. Berkeley, CA, 1994
7. Osaka, Japan ,1996

Exchanges of technologies at these workshops greatly accelerated the adoption of protective systems in both countries and the improvement and implementation of retrofit strategies.

3.2.4 Professional Networking

Participants from the United States and Japan have formed mutual friendships and established professional networks during past workshops. This naturally helps people stay up-to-date with industry practices and share information with each other. In addition to networking, participants have set up joint networking groups to discuss topics of mutual interest and to share innovative ideas. This has become an effective way to further expand professional development of experts on both sides.

Many participants consider the workshops as "out-of-the-box" brainstorming sessions. The workshop participants have taken the opportunity to openly ask questions that are normally difficult to cover in written communication or published reports. By combining the open discussion with presentations and joint publications, mutual trust has become one of the main benefits of the workshops and has laid a foundation for joint improvements.

3.2.5 Personnel Exchanges and Training

A total of 23 engineers and researchers have participated in the exchange program between 1983 and 2014—16 individuals from Japan and seven from the United States. The sixteen Japanese members had the opportunity to stay or visit the FHWA and state DOTs in the United States. This has allowed them to directly exchange information and to learn from various events such as the 1994 Northridge Earthquake, the 2005 Hurricane Katrina, and the 2012 Hurricane Sandy (*9*). The seven participants from the United States have conducted short visits or stays for exchange of technologies at the PWRI in Japan.

3.2.6 Reconnaissance

The performance of bridges in historic and damaging earthquakes has influenced the research agenda in both countries, spurring inquiry into areas such as the development of earthquake protective systems and bridge retrofit technologies (*8*). Reconnaissance efforts have subsequently led to improved design specifications for both conventional and isolated bridges, and to the development of seismic retrofitting manuals for highway structures.

The U.S.-Japan workshops have facilitated the reconnaissance efforts of the earthquakes including visiting bridges in areas impacted by several major earthquakes. As mentioned earlier, bridge engineers from the United States and Japan visited and inspected bridges in the areas affected by the Northridge Earthquake (California) in 1994, the Hyogoken Nanbu (Kobe) Earthquake in 1995, the Maule Earthquake (Chile) in 2010, and the Great East Japan (Tohoku)

Earthquake in 2011. Recent research programs on duration effects of strong ground motion and tsunami loads are direct outcomes of the 2011 Great East Japan Earthquake.

Similar to the earthquakes, reconnaissance efforts were also made to other devastating events such as hurricanes. For example, after the Hurricane Sandy struck New York and caused severe flooding damage in 2012, the U.S.-side provided the Japanese reconnaissance team with first-hand information on the damage. The Japanese reconnaissance team also benefited from the exchanges on the U.S. response schemes and preparation.

3.2.7 Response and Recovery from Devastating Events

Joint reconnaissance of devastating earthquakes and tsunamis has been crucial for both countries to enhance their abilities to handle these extreme events. These events have had serious impact on human life and property. Consequently, sharing the experiences on how to promptly respond and recover from the devastating events is extremely valuable to both countries. The exchange of experiences includes (1) proper planning and preparation for disaster, (2) prompt response to disaster, and (3) quick recovery from disaster.

Due to Japan's history with large earthquakes and tsunamis, Japan is uniquely qualified to document these devastating events. The emergency management system that Japan has developed allows it to perform immediate assessment of damage within hours of occurrence of an event and to start repair work within days. Japan has established an efficient communication system with various crews, bureau staffs, consultants and contractors who assist with assessment, repairs, and reconstruction. Its use of temporary bridges and the speed of design and repair actions have been outstanding (*5*). All of these valuable experiences are helpful to the United States in demonstrating how proper preparation improves response and recovery from a natural disaster such as an earthquake. Engineers in the United States have benefited from the experiences and lessons learned by their Japanese counterparts in managing, responding to, and recovering from extreme earthquakes, tsunamis and other disasters. Similarly, U.S. participants have shared their experiences with recent hurricanes with their Japanese counterparts.

Chapter 4. Suggestions and Recommendations

The close collaboration between the United States and Japan in planning and implementing the bridge engineering workshop for the past 30 years has resulted in significant benefits to both countries. These collaborations have also promoted the advancement of state-of-the-art technologies for bridge engineering. The success of the workshop is owed, in large part, to the strong leadership of the FHWA and the PWRI, as well as Dr. W. Phil Yen, the U.S. chair, and Mr. Hiroshi Matsuura, the Japan chair; and former chairs from both sides in the past workshops. The two chairs have worked closely and effectively over the years to lead highly productive workshops that have helped both countries in the area of bridge engineering.

It should be recognized that there are still a number of challenges facing both countries that should be addressed in future workshops. Issues such as geographical differences, language barriers, and time differences may have hindered interaction and communication among the workshop attendees. Limited funding support for the annual workshops has also been a continuing challenge. Additional support would have allowed more involvement from potential participants and more widespread benefits.

This chapter presents suggestions and recommendations to foster further collaboration and overcome some of these challenges. The suggestions and recommendations focus on six areas: (1) sharing and exchange of technologies, (2) co-operative research programs, (3) specialty area collaboration, (4) professional networking, (5) outreach, and (6) possible funding mechanisms.

4.1 Sharing and Exchange of Technologies

Throughout the 30-year history of the workshops, sharing and exchange of technologies among engineers and researchers from the United States and Japan has been extensive. Over 1,000 research papers have been presented at the workshops and published in workshop proceedings. The topics of the papers and presentations are in areas of bridge engineering that are of interest to both countries.

Future workshops should take advantage of various communications media, including the Internet and cloud storage, to improve the efficiency and effectiveness of workshop sessions and activities. Additionally, planning efforts for future workshops should be enhanced, including selection of new and timely topics such as curved bridges and spliced girder bridges.

Means of communications

The degree of success of the workshops is directly linked to simplified and efficient communications between the two countries. It is important to have wide-ranging and varied methods of communications. The primary form of communications for the workshops will likely continue to be face-to-face communication, as there is no substitute for personal interaction in developing close relationships and facilitating future interactions (*9*). Other means of communications, such as video web conferencing and online webinars, should also be mobilized.

Conferencing services allow for real-time point-to-point communications, as well as multicast communications from one sender to a number of receivers. Web conferencing permits data streams of text-based messages, as well as voice and video chats, to be shared simultaneously across geographically-dispersed locations. These methods of communications would be particularly helpful for those who are unable to attend the workshop in person, but who still want to be involved. Web teleconferencing could be provided along with face-to-face meetings or, preferably, alternate with face-to-face meetings. In either case, it is recommended that participants be required to attend a minimum number of face-to-face meetings.

Online webinars should be held on a regular basis in order to facilitate collaboration efforts. As highly cost-effective communication tools, online webinars could be presented on specific topics in order to reach targeted audiences. It should be pointed out, however, that online webinars have their own challenges, including language barriers and time zone differences. Simultaneous interpretation from English to Japanese and vice versa could be offered in order to overcome language barriers. The time zone difference of about 12 hours between the United States and Japan is more problematic. However, any inconveniences caused by time differences are negligible considering the effectiveness of online webinars in disseminating information to a large number of participants at one time. For the purposes of scheduling webinars, it is suggested that one or two fixed times of the day and month be considered. For example, a webinar could be scheduled for the second Tuesday of each month at 4:00 PM U.S. Pacific Time, 7:00 PM U.S. Eastern Time and 8:00 AM (Wednesday) Japan Standard Time.

Topics of discussion

Planning for prior workshops has been effective due to excellent collaboration among the representatives from the various entities involved in the planning activities. This planning process should be maintained and enhanced in order to boost the value of the workshops. Enhanced planning could result in increasing participants' expectations and interest in the workshops, and realizing additional benefits for both countries.

One way to improve the planning process is to utilize online surveys to assist in determining appropriate topics for new workshops. Past attendees could be surveyed to collect their input on topics of interest. Additionally, relevant professional organizations could be contacted to gather suggestions on possible topics. Future topics, including those suggested by past attendees who responded to the survey conducted for this report, are summarized herein. It is strongly recommended that seed funding be made available for any enhanced planning activities.

Online survey. An online survey could be an effective way of identifying "hot" topics for future workshops. A survey could also be used to solicit recommendations for efficient planning and conduct of future workshops, and for disseminating the outcomes of these workshops. Compared to traditional methods such as email and telephone, an online survey has a number of advantages:

- Time savings: Rapid deployment and turnaround times are possible with online surveys as opposed to traditional methods.
- Automation and ease of analysis: Respondents can input their own responses, which are stored electronically. Analysis of the surveys can be streamlined.

- Convenience for respondents: Surveys can include a full list of possible topics. The respondents would only be expected to choose their preferred topics of interest.

Collaboration with professional organizations. Close collaboration with relevant professional organizations would be beneficial for the workshop. Bridge-related professional organizations include the Precast/Prestressed Concrete Institute (PCI), the American Segmental Bridge Institute (ASBI), and the American Institute of Steel Construction (AISC) in the United States. All of these organizations host annual conventions or meetings to exchange state-of-the-art technologies for bridge engineering. By engaging these organizations prior to a planned workshop, assistance would be available in determining hot topics and possible candidates for keynote speakers and presentations. Other associated conferences such as the National Seismic Conference on Bridges and Highways in the United States could be considered as well.

Specific topics suggested for future workshops. As part of the preparation of this report, a survey questionnaire was distributed to attendees of past workshops. One of the questions in the survey solicited suggestions for future topics. The responses received reflect participants' expectations for future discussions. Examples of the topics mentioned in the responses from Japanese participants are given below (*9*):

- Performing studies on policy-making to set different performance levels of routes and to allocate resources for seismic upgrading/retrofit, bridge inspection, and rehabilitation: These studies are crucial to assist decision-makers to generate relevant policies and provisions and to properly allocate resources for routine bridge design, retrofit, construction, and maintenance.
- Designing for extreme events including tsunami effects and multi-hazard emergencies: There still has been an extensive amount of uncertainty in understanding the devastating events such as a tsunami, which necessitates further collaboration between two countries, as both of them share a commitment to maintain safe bridge structures subject to those extreme events.
- Developing joint efforts on the investigation of detection methods, causes, and repairs of fractures in aging bridge structures: There have been increased concerns over fractures that are found in existing steel bridges. Since a significant amount of steel bridges are fracture-critical structures, it results in increased maintenance and inspection costs. Therefore, it will be beneficial for both countries to work closely in investigating effective detection methods, identifying the causes of fractures, and determining the appropriate repairs of the deficiencies.
- Sharing information of both good and poor practices in bridge design and maintenance: Not only do both countries benefit from each other sharing their good practices, but also it is advantageous to exchange poor design or detailing so that subsequent harm can be avoided. For instance, the lessons learned from the collapse of the Minneapolis Interstate 35W Bridge over the Mississippi River have been beneficial to the Japan-side in improving their design practices.

It is worth pointing out that new topics will emerge as bridge technologies advance. As a result, workshops need to be adaptive in order to consider new topics and subjects. From this perspective, the following topics are suggested for possible discussion at future workshops:

- Creative construction management and funding methods such as public-private partnerships, which allow governments to bring in new sources of funding for public infrastructure and service needs.
- Concepts such as damage- or maintenance-free structure design.
- Precast/prestressed curved concrete girders in highway bridges.
- High performance construction materials, such as rapid setting grouts.

4.2 Co-operative Research Programs

The workshop activities have produced initiatives and cooperative research such as the seismic design method and seismic retrofit technologies. It is expected that the research results will be utilized not only in the United States and Japan, but also in other high seismicity areas worldwide. This can possibly be achieved by extending the technology exchanges to a selected group of personnel from other countries.

Potential funding from the United States and Japan for cooperative research projects should be sought. This will allow the sharing of resources, including personnel and facilities, and avoid possible duplication of efforts. It will also facilitate more effective and closer collaborations by incorporating the efforts of pioneers from both countries to advance the technology.

4.3 Specialty Area Collaboration

A total of seven collaborative workshops were held between 1990 and 1996 that focused on specialty areas such as seismic retrofitting and earthquake protective systems. As a result, protective seismic systems have been adopted by both countries and implementation of retrofit strategies has been significantly expedited.

Similar workshops could be held on a regular basis so that attendees can focus on one topic and resolve issues more efficiently. If possible, relevant experts from both countries could co-author and publish state-of-the-art technical reports on these specialty areas. These reports will be valuable for both countries to further improve their understanding of these areas and make more significant, expeditious technological advances.

4.4 Expanding Professional Networking

Approximately 900 participants from both countries have attended the U.S.-Japan Bridge Engineering Workshop since 1984. Some participants have attended multiple workshops. An extensive professional network has developed over the long history of the workshops. Many attendees have participated in various activities over the years, including the workshops, co-operative research programs, collaborative meetings, personnel exchange programs, and reconnaissance meetings.

There are many ways to expand this extensive professional network. It is suggested that workshop participants take advantage of social media such as LinkedIn and Facebook. Social media provides a platform that connects people and companies with similar interests in order to share information and to enhance professional collaborations. Members of these networks can ask questions; get feedback on certain topics; and share blogs, notes, and pictures of events. They can also comment on what other professionals post online, and exchange ideas and suggestions.

Another suggestion is to create an official Internet forum that would allow real-time communication among the workshop attendees. Members could create and log into their accounts, post technical questions, and share the information within the group. The forum would create a discussion environment in which members could post information on a diverse range of topics for other members to view and respond at any time. Online communities would be formed because members would often return to the site to read updates on certain topics of interest. Relationships would be developed and enhanced among members through active comments and posts. Most importantly, these exchanges would be significantly expanded without being limited to only a few occasions per year and without concerns of geographical and time differences.

4.5 Outreach and Enlarging the Attendee Base

Participation for the past workshops was by invitation only (*6, 7*)*,* which might have limited the number of attendees. Whenever possible, outreach is suggested to expand and broaden the attendee base and include more professionals from the two countries, especially those in middle management.

Young members, including those from governmental agencies and private firms, as well as students, should be encouraged to get more involved. Participation by young members will add to the foundation that has already been built by experienced participants and assist young people in their professional development.

Persons in entry level middle management positions may have limited resources to travel. A special fund could be created to encourage their participation in the workshop. A similar program has been in place at the Precast/Prestressed Concrete Institute. This program provides funds for travel expenses for government employees whose participation is important but whose agencies have limited travel budgets. This highly successful program could serve as a model for the type of program needed to foster the participation of young professionals.

4.6 Possible Funding Mechanisms

Funding for workshops in the United States has been provided by a number of entities over the years, including the National Science Foundation, the Multidisciplinary Center for Earthquake Engineering Research, and the FHWA. The funding has been awarded to a number of universities to organize the workshops, primarily the University of Nevada–Reno, and other universities such as the University of Southern California and Princeton University. This funding has also covered U.S. participants’ costs for travel, registration, and meals at individual workshops. The FHWA has been the primary U.S. funding source since the early 1990s. The U.S. chair of the workshop seeks renewal of the funding from the agency every five years.

It would be helpful to establish a more permanent funding mechanism for the annual workshop. It is suggested that a funding pool be set up through recurring annual sponsorship of state DOTs in the United States. This is the approach used to fund research by the National Cooperative Highway Research Program for the American Association of State Highway and Transportation Officials, the umbrella organization for all fifty states.

Adding an exhibit area and program to the Bridge Workshop could provide an additional revenue source. Contractors, suppliers, and manufacturers of bridge products could display their products and technologies to workshop participants. These exhibits would help participants become more familiar with the latest product developments and would provide opportunities for participants to directly interact with the exhibiting sponsors. The organizing committee could consider expanding the program to three days, with a one-day program for government-to-government discussions, a one-day program for the Bridge Workshop as it stands to date and a third day for exhibits and demonstrations from the private sector.

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Appendix II. Personnel Exchanges between 1983 and 2014

Under the FHWA/MLIT personnel exchange program, engineers and researchers are invited to stay in the other country for one week to one year to exchange the technologies and jointly perform specific studies. The following 23 engineers and researchers joined the personnel exchange program between 1983 and 2014:

Table II-1. Participants of the personnel exchange program.

Name	Affiliation	Purpose	Visiting Period
U.S. engineers and researchers who visited Japan			
Mr. Li-Hong Sheng	Caltrans	Comparison of seismic design specifications for bridges in both countries	May 2004 (4 weeks)
Dr. Ahmad Itani	University of Nevada-Reno	Earthquake protective systems for long-span bridge structures	March 2003 (3 weeks)
Dr. Hamid Ghasemi	FHWA	Seismic isolation bearing study	March 1996 (4 weeks)
Dr. W. Phillip Yen	FHWA	US-Japan seismic design comparison	March 1995 (3 weeks)
Mr. Michael Britt	FHWA	Bridge design	1994 (12 months)
Mr. Mark Yashinski	Caltrans	Seismic design	May 1994 (12 months)
Mr. Moshen Sultan	Caltrans	Bridge design	1991 (12 months)
Japanese engineers and researchers who visited the United States			
Mr. Hidesada Kanaji	Hanshin Expressway Inc.	Seismic design and bridge management system	2000 (9 months)
Dr. Shigeki Unjoh	PWRI	Guidelines for seismic isolation	2000 (1 week)
Dr. Junichi Hoshkuma	PWRI	Seismic retrofitting of bridge columns	1998 (12 months)
Dr. Hideki Sugita	PWRI	Seismic information system	1997 (2 weeks)
Mr. Toru Terayama	PWRI	Seismic retrofitting of highway bridges	1996 (1 week)
Mr. Sentaro Takagi	Tokyo Metropolitan Government	Bridge management system and inspection	1996 (6 months)

		program	
Mr. Kazuhiro Nagaya	PWRI	Seismic retrofitting of highway bridges	1996 (1 week)
Mr. Tomofumi Nozaki	PWRI	Transportation statistical analysis	1995 (12 months)
Dr. Hisonari Otsuka	PWRI	Bridge column design comparison	1995 (1 week)
Mr. Junzo. Inoue	PWRI	Bridge maintenance and management	1991 (5 months)
Mr. Keiichi Tamura	PWRI	Bridge engineering	1990
Mr. Kinji Hasegawa	PWRI	Bridge engineering	1990
Mr. Shigeki Unjoh	PWRI	Bridge engineering	April 1989 (12 months)
Mr. Koichi Minosaku	PWRI	Seismic performance of bridge piers and columns	September 1986 (10 months)
Dr. Hirohiko Tada	PWRI	Bridge engineering	August 1985 (1 month)
Mr. Ryoji Hagiwara	PWRI	Large scale testing on reinforced concrete columns	February 1983 (6 months)

Appendix III. Questionnaire Sent to Past Attendees

Questionnaire for the U.S.-Japan Bridge Engineering Workshop Attendees

Questions:

1. Please supply the following information:
   a. Name ______________________________
   b. Title ______________________________
   c. Address____
   d. E-mail address____
   e. Best telephone number to contact you ______________________
   f. Please indicate best time when we can call you, relative to U.S. Central Time
   g. Brief description of employment and bridge engineering experience (2-5 sentences)
   ____
   ____
   ____
   ____

2. Describe the nature of your employment. Circle the one(s) that apply:
   - Government
   - University
   - Non-profit organization
   - Consulting firm
   - Contractor
   - Supplier (precast concrete, structural steel, accessories, etc.)
   - Other; Specify: ______________________________

3. How many US-Japan Bridge Engineering workshops have you participated in?

   ____

4. Below is a list of topics discussed in past workshops. Circle all the ones that you are interested in.
   - Bridge design
   - Bridge rating
   - Health monitoring
   - Bridge repair and rehabilitation
   - Bridge inspection
   - Seismic engineering
   - Bridge damage

- Seismic retrofit
- Earthquake case histories
- New construction methods (such as accelerated bridge construction)
- Failure investigation
- Management and maintenance
- Codes and specifications
- Policy
- Design-build
- Private public partnerships
- High performance materials
- Geotechnical engineering

5. Describe the benefits experienced from the U.S.-Japan Bridge Engineering Workshop collaboration:

    - Personal growth: (explain)
    - New friendships and networking:
    - Personnel exchanges:
    - Initiated research and development:
    - Technical knowledge: (explain)
    - Change in practice: (explain)
    - New concepts for design: (explain)
    - New information on construction methods: (explain)

- New information on health monitoring: (explain)
- New concepts for repair (retrofit):

- New information on materials:

- Codes, specifications, and policies

- Other:

6. Suggest topics in future workshops that will be interesting or beneficial to the group.

7. Suggest improvements in format for future workshops.

8. Please dig deep into your memory. We are interested in events that took place in past workshops and/or follow-up interactions that we cannot detect on our own from workshop proceedings. These events include, but are not limited to, histories of joint collaboration, trends of topics, introduction of bridge site visits, implementation of personnel change program, co-operation on research programs, etc. Please mention the event/idea/conversation that will allow us to follow up in future communication.

9. Please explain what your participation in the workshops meant to your organization.

Appendix IV. Summarized Transcripts of Interviews

The project team has conducted face-to-face interviews with Dr. W. Phil Yen, the U.S. chair of the U.S.-Japan Bridge Engineering Workshop and Principal Bridge Engineer at the FHWA, and Ms. Agnes R. Vélez, Project Manager and Transportation Specialist at the FHWA. The team also has conducted phone interviews with Dr. David Sanders, the U.S.-side workshop organizer and Professor at the UNR, and Dr. Ian Buckle, Professor at the UNR. The team has contacted the staff at the PWRI including Mr. Hiroshi Matsuura, the Japan-side Chair; Mr. Shigeki Unjoh; Mr. Hitoshi Tajima; and Mr. Hideaki Nishida. All the people interviewed or contacted by the project team have provided valuable input. Their input is included herein.

IV.1 Input from Dr. W. Phil Yen, the U.S. Chair of the Workshop

The key accomplishments and benefits of the workshops are summarized as follows:

- Japanese Bridge Technology: The United States has learned a great deal from outreach activities with Japan. There are a number of technologies that were made or tested/proven in Japan with regard to bridge seismic retrofitting measures, such as:
    - Restrainers, steel or concrete Jackets & Fiber Reinforced Polymer Jackets for columns shear strengthening and ductility increasing, which have been adapted or revised to use in the high seismicity area of the United States (California, Washington, Oregon).
    - Isolation bearings, such as High Damping Rubber Bearing and Friction Pendulum Isolators, are used commonly in the West Coast states, as well as in the central U.S. (i.e., Tennessee & Missouri).

- Japanese technology and methods of seismic design detail in ABC were also exchanged and are considered in the development of seismic design guidelines in prefabricating bridge column/piers.

- Recovery technology and emergency planning lessons learned from large earthquakes and a tsunami have also helped improve our technology and methodologies in the United States in handling extreme events. Weathering steel with special treatments used in the northern part of Japan (Hokkaido island), introduced and discussed during the bridge workshops, has influenced East Coast states to adopt using more weathering steel for bridge superstructures.

IV.2 Input from Dr. David Sanders, the U.S. organizer and Professor at UNR

- As the U.S. organizer of the workshop, it is good to get to know the Japanese members of both PWRI and NILEM on a professional and personal level.

- It is beneficial to share the latest technologies between these two countries.

- Exchange of information occurred at the workshops and also at the technical site visits.

- The Great East Japan Earthquake subjected a significant area to large ground motions and then to the tremendous effect of the tsunami. The workshop provides the U.S. valuable information on these disasters.

- It is critical for the United States to be sure that we are prepared for possible earthquakes and tsunamis and also know how to respond quickly.

IV.3 Input from Dr. Ian Buckle, Professor at UNR

1. In the early nineties, the success of the U.S.-Japan Bridge Engineering Workshops led to a separate set of collaborative meetings focused on specialty areas such as seismic retrofitting and earthquake protective systems. In total seven meetings (workshops) were held from 1990 to 1996 as follows:

   Four U.S.-Japan Workshops on *Earthquake Protective Systems for Bridges*
   1) Buffalo, NY, 1992
   2) Tsukuba, Japan, 1992
   3) Buffalo, NY, 1994
   4) Osaka, Japan, 1996

   Three U.S.-Japan Workshops on *Seismic Retrofit of Bridges*
   1) Tsukuba, Japan, 1990
   2) Berkeley, CA, 1994
   3) Osaka, Japan 1996

   Exchange of detailed technical information at these meetings greatly advanced the adoption of protective systems in both countries and the improvement and implementation of retrofit strategies.

2. Connections made at the U.S.-Japan Bridge Engineering Workshops greatly facilitated the reconnaissance efforts by:
   1) Japanese researchers and practitioners following the Northridge Earthquake, CA, in 1994
   2) U.S. researchers and practitioners following the Hyogoken Nanbu (Kobe) Earthquake of 1995
   3) U.S. and Japanese researchers and practitioners following the Maule Earthquake, Chile, 2010, and
   4) U.S. researchers and practitioners following the Great East Japan (Tohoku) Earthquake of 2011.

   The performance of bridges during these historic earthquakes influenced the research agenda in both countries for many years, such as the development of earthquake protective systems and bridge retrofit technologies. This effort subsequently led to improved design specifications for both conventional and isolated bridges, and the development of seismic retrofitting manuals for highway structures. Today, research programs in duration and tsunami loads are direct outcomes of the 2011 Great East Japan Earthquake. Given the complexity of the tsunami problem, a collaborative research program has been established between the United States and Japan to improve the numerical modeling of tsunami effects, and developing design procedures that have been validated in wave basin experiments.

3. Earthquake engineering is a challenging endeavor where it is not possible to make progress quickly. This is because damaging earthquakes are rare and learning from earthquakes is a slow and painful process. But society demands answers and engineers are required to make decisions based on limited facts and evolving science. This is a profoundly difficult problem

because the quality of these decisions affects the safety of millions of people living worldwide in seismically active areas. One way to grow the knowledge base on which these decisions are made, is to share experiences with a country like Japan which has an extremely high standard of engineering. The opportunity for an annual exchange of such experiences at the United States-Japan Workshops has therefore been priceless.

IV.4 Input from the Active Participants at the PWRI

1. Please describe significant events that took place at past workshops and/or follow-up interactions that we may not be able to discover from workshop proceedings.

Question 1) *Please talk about histories of joint collaboration.*

Question 2) *Please describe significant events on co-operation on research programs.*

Question 3) *Please talk about trends of topics.*

Question 4) *Please address the implementation of personnel exchange program.*

Question 5) *Please describe any other significant events that you are aware of.*

Japanese members joined a lot of co-operative research programs with the U.S. members, and these programs were very effective for us to improve or develop the design codes, construction methods, and maintenance technology for bridges

- ✓ U.S.-Japan Workshop on Seismic Retrofit of Bridges (3 workshops)
- ✓ U.S.-Japan Workshop on Earthquake Protective Systems for Bridges (4 workshops)
- ✓ Development of Draft Guidelines for Experimental Verification of Seismic Performance of Bridges (Quasi-Static Cyclic Loading Tests and Shake Table Tests for Bridge Columns)
- ✓ A Comparative Study of U.S.-Japan Seismic Design of Highway Bridges
- ✓ U.S.-Japan Joint Reconnaissance of Damaged Bridges due to Earthquake: 1994 Northridge,1995 Hyogo-ken Nambu, 2010 Chile, 2011 Tohoku
- ✓ Many visits and short/long stay at our institute from FHWA, state DOTs

If you would like to get more information about past activities, please check the following webpage.

http://www.pwri.go.jp/eng/ujnr/ujnr.htm

Especially, the past events concerning this workshop will be found in the task committee G reports which were made at the joint meetings.

2. **Based on your personal experience, would you please summarize the benefits of the past workshop collaboration?**

Question 1) *Please talk about the benefits of new friendships and networking.*
Japanese participants could make a lot of friends and network in their specialized field shop during each workshop.

Question 2) *Please summarize the benefits of personnel exchanges.*

Many Japanese members have opportunities to stay or visit the U.S. to get information and to learn lessons from the disasters and accidents including 1994 Northridge, 2005 Katrina, 2012 Sandy and so on.

Question 3) *Please address the benefits of initiated research and development.*

We have conducted cooperative research projects: for example, a comparative study of seismic design methods in U.S. and Japan, seismic control systems, and seismic testing protocol. The results were jointly published in journal papers and reports.

Question 4) *Please talk about the benefits of technical knowledge exchange such as new technology for design, construction, repair, health monitoring, and materials, and enhancement in codes, specifications, and policies, etc.*

Workshops have provided us the latest technical information, including code and standard revision, new technology development, research interest areas, governmental policies, and disaster investigation information in the U.S. Such detailed information is extremely useful for us.

- New concepts for design: (explain)
  For example, we learn so much about the seismic ductility design method and the capacity design concept. And new design concepts for new S.F. Bay Bridges (mono cable) are also useful information.

- New information on construction methods: (explain)
  Accelerated Bridge Construction (ABC) concept.

- New information on health monitoring: (explain)
  Information on monitoring sensors which were employed for I-35W reconstruction project.

- New concepts for repair (retrofit):
  Seismic retrofit methods, including steel jacketing methods for concrete columns and the details such as the gap concept at the bottom of columns. Seismic retrofit projects for long-span bridges in California.

- New information on materials
- Codes, specifications, and policies

  Recent information on AASHTO design specifications and Caltrans design manuals.

  Concept and present issues of Load and Resistance Factor Design (LRFD),

  Concept and present issues of LRFR for existing bridges.

Question 5) *Please describe other benefits.*

3. **We would like to know your expectation on future workshops.**

Question 1) *Please talk about your suggestions on the format of future workshops.*

Face-to-face meetings are still very important to develop close relations and to work closely. Moreover, the web conference system is another option to make our cooperative researches more active.

Question 2) *Do you have any recommendations on future topics?*

- Study on policy making to set different performance levels of routes and allocate resources for seismic upgrading/retrofit, bridge inspection, and rehabilitation
- Design for Extreme Events including Tsunami Effect, Multi-Hazard
- With increasing concerns over structural member fractures of aging bridges in the United States and Japan, we will conduct joint efforts to investigate detection methods, causes and repairs.
- Share information on the best and poor practices in bridge design and maintenance

Question 3) *Please talk about your thoughts on the outreach.*

Task committee G has produced outcomes of cooperative research tasks on the seismic design method, seismic retrofit skills, and so on. Japan-side members hope that these excellent outcomes will be utilized not only by the United States and Japan, but also in high seismic areas worldwide.

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