The American Society of Civil Engineers
Structural Engineering Institute

– Bridge Workshop –

Enhancing Bridge Performance

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Reston, Virginia

Workshop Report

Prepared by the

Technical Administrative Committee (TAC) on Bridges

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About the Workshop
Members of the structural engineering community gathered for an invitation-only two-day workshop held February 21-22, 2008, in Reston, Virginia. See Appendices A, B, and C of this report for workshop agenda, speaker biographies, and a list of participants. The purpose of the workshop, hosted by ASCE/SEI and co-sponsored by the FHWA, was to set an agenda of critical needs for enhancing the performance of bridges. This report documents the activities and products of the workshop.

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1. EXECUTIVE SUMMARY

The Structural Engineering Institute of the American Society of Civil Engineers (ASCE/SEI) “Enhancing Bridge Performance” Workshop was convened to bring together the structural engineering community from ASCE, the Federal Highway Administration (FHWA), Departments of Transportation (DOTs), the design and construction industry, and academia from across the country to set an agenda of critical needs for enhancing the performance of bridges. The invitation-only two-day workshop was co-sponsored by the FHWA and was structured according to the six ASCE/SEI Bridge Technical Committees under the Bridge Technical Administrative Committee (TAC): Bridge Management, Inspection and Rehabilitation; Steel Bridges; Timber Bridges; Concrete Bridges; Cable Supported Bridges; and Bridge Security.

Transportation infrastructure is important to the flow of people and goods and for a healthy economy. The highway network becomes critical in times of hazard events for evacuation and afterwards for response and recovery. It is essential that the network stays open so that a hazard does not become a major disaster event. Bridges being critical links, it is important for any nation to maintain these in good and safe working condition. However, this is becoming a challenge in the United States and a challenge for bridge engineers with the aging of the bridge population. The National Bridge Inventory (NBI), a database maintained by the FHWA, consists of approximately 600,000 publicly-owned vehicular bridges that are greater than 20 ft in length. The average age of this inventory exceeds 44 years, and approximately 25 percent is classified as being structurally deficient or functionally obsolete.

Questions arise concerning what is needed most to enhance the performance of the nation’s bridges at this time. Is what is needed most for concrete bridges the same items as are needed most for steel or timber bridges? What is most critical for the existing and newer cable-supported bridges? How does bridge security factor into these needs in a post 9/11 world?

Questions also arise about bridge inspection and bridge monitoring – can these help us enhance bridge performance, is what is currently being done adequate, and what more is needed to improve our understanding? In an effort to maintain safe bridges, states are mandated to inspect each bridge once every two years (with minimal exceptions). While many states collect detailed bridge inspection data, the NBI data fields submitted annually to the FHWA are limited. The FHWA compiles and analyzes this limited data for various purposes, including reporting the condition of the nation’s bridges to Congress. Examples of NBI data analyses include the count of bridges by material type and year built, the count of bridges by material type and deficiency, and the count of bridges by structure type and deficiency (see Appendix G). Questions that need to be addressed include what information on performance is needed, how more accurate information can be collected, types of information to determine the performance of new materials, types of information that would help before and after an extreme event, and technology currently available to address these needs.

The evolution of bridge technology has come about with improvements in science and hence structural theories, but by far, through improvements in construction material technology. The long span suspension bridges became possible only after the development of high strength wires. Today with the development of new advanced materials such as high performance concrete, high performance steel, fiber reinforced polymers, and advanced wood composites, new possibilities emerge. The majority of today's bridges were designed based on knowledge that is at least 50 years old. If things are to change, we need to move forward beyond incremental improvements, but this requires risk taking which has been difficult to do for infrastructure owners. Looking ahead we can see the possibilities of new bridge designs and systems being developed utilizing better materials; however, we also have a large investment in our existing inventory that needs to be maintained to safely carry growing traffic needs through proper inspection and maintenance. Although there is a law requiring routine bridge safety inspections every two years, the shortfall with current inspection methodology is that it is largely based on visual inspections that can be subjective. Although Non-Destructive Evaluation (NDE) technologies exist that can detect defects and provide quantitative information about the member being inspected, there are challenges that remain. These include being able to rapidly evaluate deterioration in all materials and member types, improving the reliability and quality of inspection methods, standardization of the technologies, and the costs.

A 20-year program monitoring performance of bridges is being initiated by the FHWA. It is hoped that the data generated on bridge performance over this long-term period will lead to enhancements in characterization of bridges, improvements in reliability of performance, better reliance on inspection data, and overall improved models predicting the condition of our bridges.

The participants to the workshop were given the charge to discuss (1) bridge design issues including best practices in design and detailing that could be used to improve durability, extend service life and prevent premature deterioration, (2) performance measures needed to better determine bridge condition, (3) technologies that could be used to monitor bridge life and assess condition, and (4) improving decision-making through comprehensive collection and evaluation of bridge performance and operations data and other topics which the groups felt were of importance.

Key Outcomes

There are many similarities in the behavior and hence performance of bridges even of different materials mostly due to similarities in design. However there are also many unique differences as a result of the differences in material used to construct these bridges. Attention to details during the design stage, construction and material quality control, drainage and moisture control, inspection frequency and inspectability were themes common to all groups. The innovations in and eventual greater use of sensors and sensing systems were perceived as positive developments for aid in inspection and condition monitoring to acquire better information on the health of bridges for all bridge types. Key outcomes are summarized below with respect to the charges given to the breakout groups.

Bridge Design

- The bridges that are designed today could last 75-100 plus years, if they are designed and constructed properly, with good quality control during material selection, fabrication and construction, and if periodic maintenance is conducted. Following best practices and with the use of new materials we can expect increased durability, extended service life, minimal deterioration, and resiliency for extreme events. However, designing for security is still at its infancy as much more research needs to be conducted.

- Some of the best practices discussed include paying attention to structural details, avoiding leaking deck joints, and providing for inspectability. Deck joints which lead to leaks can be a problem for all bridge types as it can lead to corrosion of steel in steel bridges, corrosion of reinforcing steel in concrete bridges, decay of wood in timber bridges, and corrosion of fasteners. Joint improvement would eliminate the root cause for a large percentage of corrosion and decay problems.

- The bridge design process must address performance needs and future repairs/inspections. Providing design details and performance specifications into initial designs and contract documents for more long-term durability and improved rehabilitation efforts is seen as a key for longer service life.

- In designing for security, performance-based security design that considers the four D's (Detect, Deter, Deny, Defend) should be developed as part of a consistent multi-hazard risk management process.

- A major factor which is leading to poor bridge performance and reduced service lives of timber structures was seen as being lack of sufficient education and knowledge by engineers about timber bridges (extending across the design-fabrication-construction-inspection-load ratings spectrum), because timber is the least familiar bridge material.

Performance Measures

- The processes which reduce the life of structures include improper quality assurance and quality control during fabrication, handling, storage and during construction for all material and bridge types. Many of the concrete bridge deteriorations that take place are caused by inadequate construction practices, concrete production and finishing techniques. The deterioration of timber bridges is accelerated by improper storage and handling during construction, in addition to poor detailing, inadequate drainage, improper protection of end grain areas, inadequate moisture management, and over-reliance on chemical preservative treatments. Most fatigue and fracture of steel bridges occur due to inadequate or improper detailing at the design stage and/or poor quality control at the fabrication stage. In addition to fatigue, corrosion is also a major issue with steel bridges, much of which can be alleviated with proper quality control including proper surface preparation, and proper application of paint and coating systems.

- The critical deficiency in the type of data that is currently collected in standard bridge inspection/ management practices includes the subjective nature of the inspection data. Too much reliance is given on visual inspection. It was a general feeling that the information that is currently gathered today is not adequate to judge the performance of bridges. Although visual inspection will never be replaced and does not need to be, it can be supplemented with quantitative inspection data (bridge monitoring), and better forecasting methodologies. Non-Destructive Evaluation (NDE) technologies can also supplement visual inspection.

- Concrete can deteriorate due to many causes, including cracking, scaling, delamination, spalling, chloride contamination, efflorescence, ettringite formation, honeycombs, pop-outs, wear, collision damage, abrasion, overload damage, and reinforcing steel corrosion. Direct performance measures discussed for concrete include load distribution, deflection, and strain/stress.

- Corrosion and fatigue are two major deterioration issues for steel bridges. Performance measures that lead to quantifying the remaining fatigue life, identifying the onset of problems in suspect details, and quantifying the rate of corrosion were discussed for steel bridges.

- Specific performance measures discussed for timber bridges included data on early decay detection, in-situ moisture content, and live load strain distribution.

- Issues for cable supported bridges include high strength steel wire vulnerabilities and inspectability. Performance measures discussed were detection of stages of corrosion, and effectiveness of cable protection systems.

- In terms of security, issues discussed to improve performance included providing standoff, redundancy and continuity.

Technologies to Monitor Bridge Life and Assess Condition

Technologies exist today for conducting nondestructive evaluation inspections, monitoring bridge life, and assessing bridge condition; however, not much of this is used in day-to-day operations. This may be due to a number of factors including cost, difficulty in data interpretation, life of sensors and sensing systems compared with the life of structures being investigated, rapid changes in technology, and inadequate understanding of what is needed for assessing different bridge types.

Advanced NDE technologies and techniques are needed to detect what is occurring inside the concrete bridge members, particularly to check on the condition of prestressing tendons in beams and rebars in decks as bridges age. Inspecting cables on cable supported structures is still a challenge. There has been very little advancement in new NDE tools for inspecting timber structures. As corrosion and fatigue are major issues with steel bridges, being able to detect and quantify the deterioration is still a challenge.

The needs discussed include:

- Developing early warning systems to detect onset of corrosion, the start of internal damage, and moisture content;

- Further development of embeddable sensors or remote sensing devices that can more effectively characterize defects in members;

- More work in the area of embedded array of sensors that can trigger appropriate remedial action;

- Sensors to detect damage, assess performance, evaluate repair, provide data for design, provide early warning of failure, monitor load paths and evaluate damage;

- Sensors that are durable, low cost, low power, wireless, miniature, embeddable, and with high signal/noise ratio;

- Ability to measure deflection/strain under service loads;

- Development of economical NDE inspection tools and training at the local level;

- Data to determine when and how frequently overloads occur, as common occurrence of overloads has an impact on fatigue life of structures; and

- Inventory of fatigue crack locations, and assessment of problem details, repair and retrofit procedures and effectiveness of retrofits;

Improvements in Decision Making

- The physical separation between design, construction, inspection, maintenance and research that exists today needs to be changed so that one can learn from the other and make relevant improvements. A need for a circular design process that fosters more of a life-cycle approach in all aspects was discussed.

- Routine inspection, maintenance, and load rating were areas highlighted by the Timber Bridge Committee as areas needing improvement in decision making.

- The Concrete Bridge Committee discussed at length bridge inspection /inspector needs. A key item to obtaining high quality inspections is the need to retain inspection staff; have inspectors inspect different bridges, which ensures cross checking of ratings; having a peer exchange program for inspectors; and having a specialized training and certification program for inspectors using advanced technologies.

- The Steel Bridge Committee discussed having a comprehensive collection and evaluation of bridge performance and operations data that would reflect more accurately the decisions that are made for maintenance, repair and replacement, so that resources are spent wisely.

This was the first workshop developed by the bridge technical committees of the ASCE/SEI Bridge TAC and focused on bridge deterioration issues and ways to enhance bridge performance. The next steps include sharing information discussed during the workshop with the larger bridge community including AASHTO, FHWA, consulting engineers, educators, and others, and increasing awareness to continually improve the performance of bridges across the Nation. At a future date(s) the Bridge TAC plans to address other issues of importance to the bridge community.

Many of the presentations from the Workshop have been posted on SEI's website at http://content.seinstitute.org/committees/bridges.html.

2. BACKGROUND

Transportation infrastructure is important to the flow of people and goods and for a healthy economy. The highway network becomes critical in times of hazard events for evacuation and afterwards for response and recovery. It is essential that the network stays open so that a hazard does not become a major disaster event. Bridges being critical links, it is important for any nation to maintain these in good and safe working condition. However, this is becoming a challenge in the United States and a challenge for bridge engineers with the aging of the bridge population.

The National Bridge Inventory (NBI), a database maintained by the Federal Highway Administration (FHWA), consists of approximately 600,000 publicly-owned vehicular bridges that are greater than 20 ft in length. The average age of this inventory exceeds 44 years, and approximately 25 percent is classified as being "structurally deficient" or functionally obsolete." "Structurally deficient" is a term used for a bridge with reduced load-carrying capacity and significant bridge elements with deteriorated conditions. "Functionally obsolete" is a term used for a bridge that has geometrics that do not meet current design standards. These terms are used to summarize bridge deficiencies and do not indicate that a bridge is unsafe.

Questions arise concerning what is needed most to enhance the performance of the nation's bridges at this time. Is what is needed most for concrete bridges the same items as are needed most for steel or timber bridges? What is most critical for the existing and newer cable-supported bridges? How does bridge security factor into these needs in a post 9/11 world?

Questions also arise about bridge inspection and bridge monitoring – can these help us enhance bridge performance, is what is currently being done adequate, and what more is needed to improve our understanding? In an effort to maintain safe bridges, states are mandated to inspect each bridge once every two years (with minimal exceptions). While many states collect detailed bridge inspection data, the NBI data fields submitted annually to the FHWA are limited. The FHWA compiles and analyzes this limited data for various purposes, including reporting the condition of the nation's bridges to Congress. Examples of NBI data analyses include the count of bridges by material type and year built, the count of bridges by material type and deficiency, and the count of bridges by structure type and deficiency (see Appendix G). Questions that need to be addressed include what information on performance is needed, how more accurate information can be collected, types of information to determine the performance of new materials, types of information that would help before and after a hazard loading, and technology currently available to address these needs.

The Structural Engineering Institute of the American Society of Civil Engineers (ASCE/SEI) "Enhancing Bridge Performance" Workshop was convened to bring together the structural engineering community from ASCE, the FHWA, Departments of Transportation (DOTs), the design and construction industry, and academia from across the country to set an agenda of critical needs for enhancing performance of bridges. The invitation-only two-day workshop was co-sponsored by the FHWA and was structured according to the six ASCE/SEI Bridge Technical Administrative Committees (TACs): Bridge Management, Inspection and Rehabilitation; Steel Bridges; Timber Bridges; Concrete Bridges; Cable Supported Bridges; and Bridge Security.

3. WORKSHOP OBJECTIVE AND STRUCTURE

Objective

The objective of this workshop was to gather members of the structural engineering community to set an agenda of critical needs for enhancing performance of bridges. Its focus was on bridge deterioration issues and on key data elements that could be included in measuring bridge behavior to ensure safety and long-term survivability, as well as the items needed most for the various bridge types in order to enhance overall bridge performance.

All six Bridge TAC committees participated in the workshop. This report summarizes the workshop and includes recommendations received from participants to set the agenda of critical needs. The objective of this workshop is consistent with the Grand Challenges identified in the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Bridges and Structures (SCOBS) 2005 Strategic Plan for Bridge Engineering (see Appendix H for link).

Structure

The morning of the first day participants were offered several presentations beginning with welcoming remarks from ASCE/SEI and FHWA, followed by presentations by national bridge experts that set the stage for the workshop.

The afternoon of the first day began with presentations by Chairs or their designated representatives of the six committees under the ASCE/SEI Bridge TAC on bridge deterioration issues and performance measures.

A short question-and-answer period followed with audience discussion after both the morning and afternoon presentations.

The second day was set aside for the audience to provide input through smaller breakout group discussions on means to enhance bridge performance. Six breakout groups were formed covering five bridge subject areas: steel, timber, concrete, cable supported and security. This grouping also aligned with the structure of the Bridge TAC. Bridge management and inspection issues were covered by all groups, and two groups were formed for the concrete subject area as a result of the number of workshop participants with interest in this area. The charge to the breakout groups was to discuss (1) bridge design issues including best practices in design and detailing that could be used to improve durability, extend service life and prevent premature deterioration, (2) performance measures needed to better determine bridge condition, (3) technologies that could be used to monitor bridge life and assess condition, and (4) improving decision-making through comprehensive collection and evaluation of bridge performance and operations data and other topics which the groups felt were of importance.

Breakout session reports were given the afternoon of the second day with a question-and-answer period and audience discussion following the session reports. Many of the presentations from the Workshop have been posted on SEI's website at http://content.seinstitute.org/committees/bridges.html.

4. WELCOMING REMARKS BY SPONSORS

The FHWA and ASCE/SEI sponsors welcomed participants to the workshop.

Sheila Rimal Duwadi, P.E., M. ASCE, Team Leader for Bridge Safety, Reliability and Security for the FHWA and the SEI Bridge TAC Chair, welcomed participants to the workshop and thanked ASCE/SEI for its partnership with FHWA in co-sponsoring the workshop. She discussed the origins of the workshop and its objective. The agenda for the two-day workshop was developed with input from the chairs and members of the six bridge technical committees under the bridge TAC, representing practicing engineers and researchers across the country. This topic was selected for its relevance and commonality to all the committees, and before the I-35W bridge collapse, but now has even more relevance as a result of that tragedy. Ms. Duwadi said the workshop organizers were looking forward to active participation of all of the individuals attending the workshop.

Jim Rossberg, P.E., M. ASCE, SEI Director, welcomed participants and thanked FHWA for its support of the workshop, and thanked the chairs and members of ASCE and other attendees for taking time from their busy schedules to participate in the workshop. He said the next two days would be spent developing ideas and recommendations on activities and partnerships with other organizations to enhance bridge performance. The next step will be to invite the bridge technical committee chairs to a follow-up meeting to take the ideas and recommendations generated at this workshop and develop a plan to move forward.

Patrick J. Natale, P.E., F. ASCE, CAE, ASCE Executive Director, welcomed participants and said that ASCE has identified bridges as one of its priorities, focusing on improving the way bridges are built, operated, and maintained. A number of the winners and finalists of the Outstanding Civil Engineering Achievement Award have been bridges, with function, safety, and aesthetics being important considerations. Security is also a priority, and ASCE was one of the founding members of The Infrastructure Security Partnership (TISP), a public-private partnership created after 9/11 to promote collaboration to improve the resilience of the nation's critical infrastructure against the adverse impacts of natural and man-made disasters. Mr. Natale said this workshop was invitation-only to get the right people here, and he appreciated the time that participants were taking from their schedules to discuss what was needed and how to get other engineers, the public, and policymakers to pay attention. Looking across the sector is valuable, and workshop participants represented a good cross-section of engineers in private practice and in government at all levels and academia. Mr. Natale said that ASCE is successful because of the partnership of volunteers and staff. He thanked FHWA for its co-sponsorship of the workshop. This workshop will help set the path to the future on what to do to improve bridge performance.

Gary L. Henderson, M. ASCE, Director of the FHWA Office of Infrastructure Research and Development, said it was appropriate this week to bring together national engineering experts because it was National Engineers Week. He said the I-35W bridge collapse is bringing national attention to bridge issues. The National Bridge Inventory of approximately 600,000 bridges has an average age exceeding 44 years, and 25 percent of these bridges are deficient. Serviceability issues over time are known. What is not known is how environmental factors, changes in loads, etc., affect service life. The public should be able to take for granted their ability to move when and where they want. Unfortunately the nation's investment has not kept pace with the impacts of aging. Addressing these challenges will require a collaborative approach by all. This workshop is an important first step to seek input on these challenges to improve bridge safety and long-term performance. The outcome of the workshop should be shared with the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Bridges and Structures and with all of FHWA. He thanked participants and wished them success.

5. SETTING THE STAGE – REMARKS BY KEYNOTE SPEAKERS

Four national experts were invited to give presentations to set the stage for discussions on the critical needs for enhancing bridge performance. Their presentations are summarized below. The question-and-answer session that followed the presentations is provided in Appendix F.

5.1 Evolution of Bridge Technology

Tom Ho, Ph.D., P.E., Vice President of T.Y. Lin International gave a presentation entitled ‘Evolution of Bridge Technology.’

The points covered included important factors in the evolution of bridge technology, and whether the early bridge builders, i.e. the Romans and the Egyptians would be able to build our bridges today if they had the construction materials of today. Below is a summary of his presentation.

Factors in bridge evolution

Dr. Ho started out by stating that four design types distinguish bridges that have been built in the several thousand years since the start of bridge building, and these include girder, arch, suspension and cable-stayed bridges. All four types have existed for millenniums, although they may not have been as sophisticated. The early bridge builders built them intuitively using naturally available construction materials such as wood, vines, and stone. Although we now have the ability to build bigger, stronger, more sophisticated, durable and predictable structures, in the last few thousand years, no new bridge design types have been invented.

The factors affecting the evolution of bridge technology have included improvements in science and hence structural theories, better construction equipment and more importantly better construction materials. Dr. Ho stressed that ‘material’ has been the most important factor in the evolution. The two dominating materials in the history of bridge construction are considered to be stone and steel. The two main eras in bridge evolution included the ‘arch era’ from about 2000 BC to 1850 AD, almost 4000 years; and the ‘contemporary era’ from about 1850 AD to now, about 160 years.

The ‘arch era’ included the use of stone as the predominant construction material. As stone is only good in compression the bridges built included only arch type designs, some of which stand today. The Romans built many spectacular arch bridges with all the arches being semi-circular. The first non-semicircular arch bridge was built in 600 AD in Zhaozhou, China with a span of 37 m and a rise of 7 m. A semi-circular bridge of the same span would have had a rise of 18.5 m. This is depicted in figure 1.

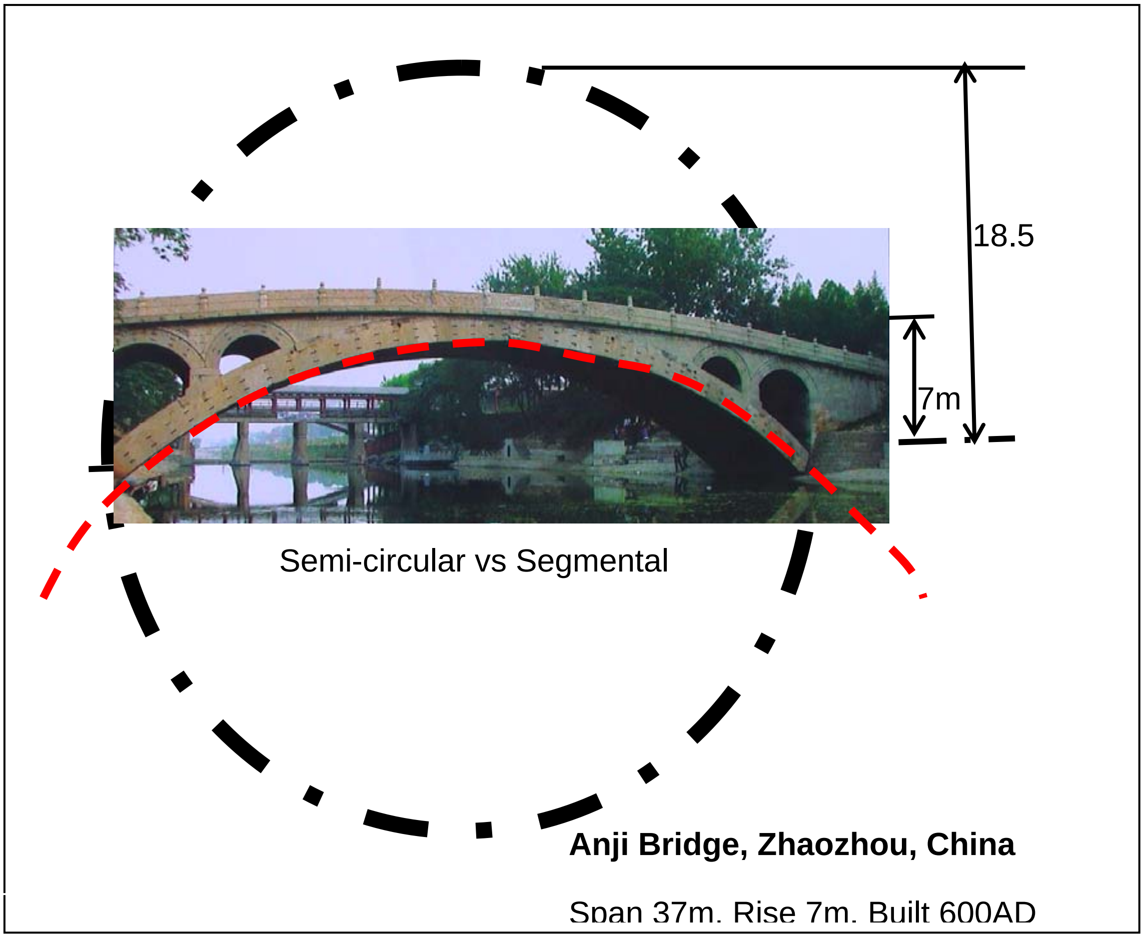

Figure 1 Anji Bridge, China

With the development of iron and then steel, the contemporary era began. Use of iron was popular for a period of time, and some large bridges were built in the form of arches and as suspension bridges with iron eye-bar chains as main cables, but the tensile capacity of iron was still limited. Mass production of steel came in the mid 1850s and changed the landscape of bridge construction. Steel began to be used in girders, as reinforcement in concrete, as wires for cables and as a prestressing material. The three landmark steel bridge structures before the 20th century were the St. Louis Bridge by James Eads in 1874, the Brooklyn Bridge by the Roeblings in 1883, and the Firth of Fourth Bridge by John Fowler and Benjamin Baker in 1889.

Long span suspension bridges became possible only after the development of high strength wires. Figure 2, from Dr. Ho's presentation, shows the span length vs year built of major suspension bridges. This figure depicts the influence of new material and how it has been used to stretch the upper bounds.

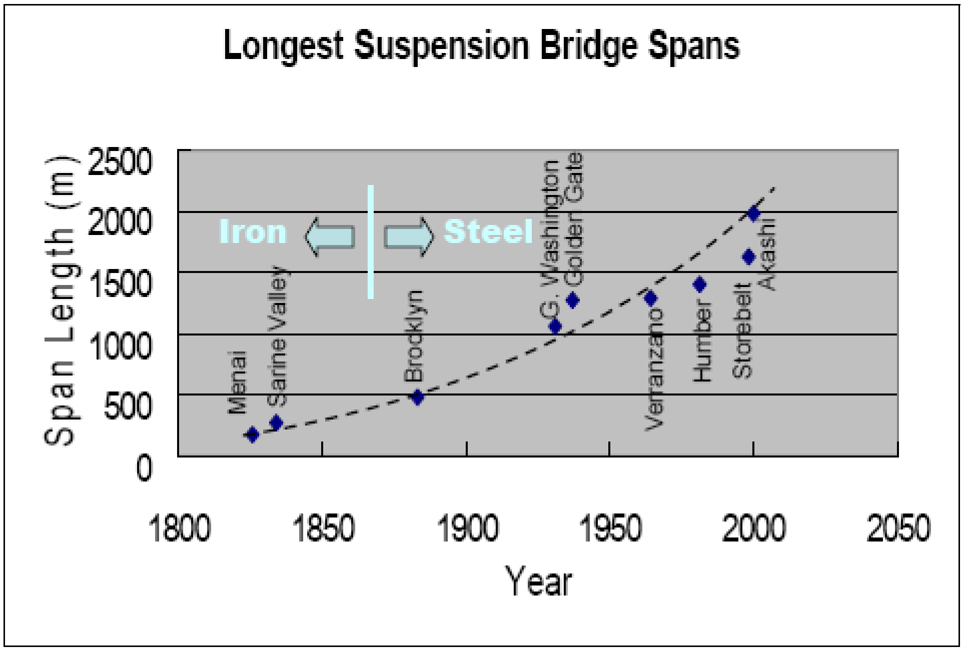

Figure 2 Suspension bridge span lengths

Development of high strength wires lead to the popularity of cable-stayed bridges. In the design of a cable stayed bridge the sag in the cables must be stressed to a very high force level to be effective and, therefore, the development of high strength wires was needed to make the design of these bridge types possible. Figure 3 shows the span length versus the year built for cable-stayed bridges.

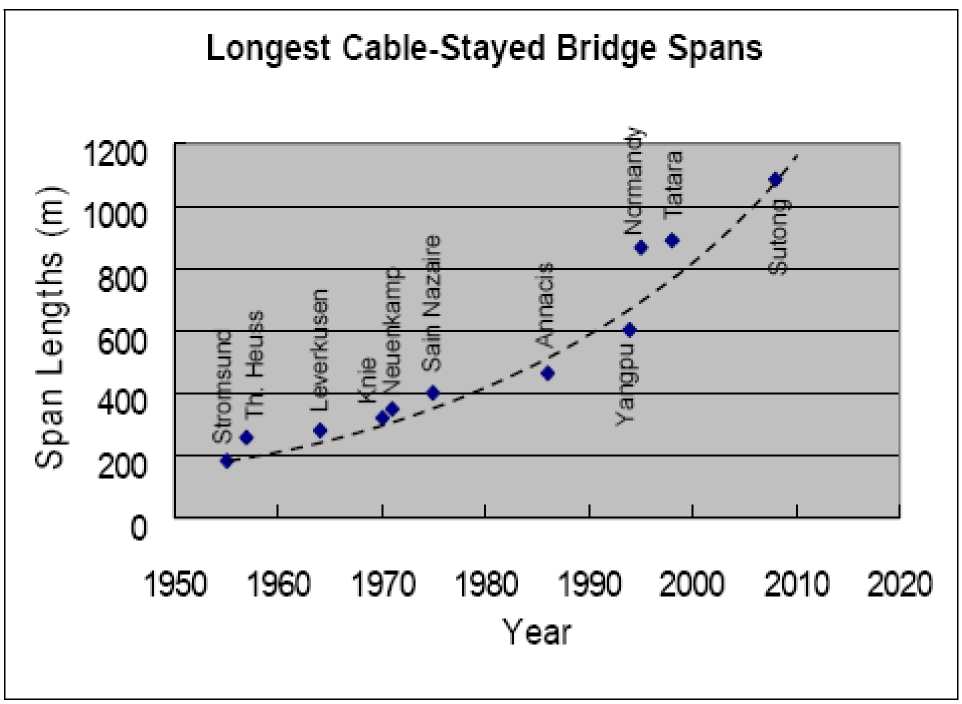

Figure 3 Cable-stayed bridge span lengths

Engineering as Art
The second point stressed in the presentation was whether the Romans and the Egyptians would be able to build our bridges if they had the construction materials we have today. To speculate they probably would as most engineering solutions came before the theories. Aerodynamics was an important issue in the longevity of suspension bridges in the early days as most failed due to wind loadings. Around 1800, James Findley patented the stiffened suspension bridge concept but most of these still failed due to wind loadings. Then in 1870 John Roebling installed inclined cables in the Wheeling Bridge which worked, mitigating the wind vibration problems.

Periods of great opportunities for building bridges included the timeframe during the expansion of the Roman Empire; the industrial revolution; the re-construction after World War II; and today in China, India and other developing countries. The expansion of the Roman Empire lead to the construction of many stone arch bridges; the industrial revolution saw the bridges built using steel; the re-construction after WWII saw the development of cable-stayed, orthotropic decks, prestressed concrete, and composite deck bridges. The next question is what new developments will result from the current construction boom in China, India and other developing countries. Today's new materials include very high strength composites and high performance concretes, and other higher performing materials, and we have yet to see what kind of evolution in bridge technology these will bring.

5.2 Enhancing Bridge Performance – A Long-Term Vision

Steven B. Chase, Ph.D., M. ASCE, Chief Scientist, retired from the Federal Highway Administration presented the needs for enhancing bridge performance. This is a summary of his presentation.

Highways are the backbone of the Nation's transportation system. Eighty-nine percent of the total dollars of freight was transported over the Nation's highways in 1997. Our highways carry over 90% of personal travel in the US, and are the transportation mode of choice. There is striking similarity between the growth of the Nation's Gross Domestic Product and the vehicle-miles traveled. There has been over a 300% growth of highway ton-miles since 1960. In 2000 there were 2.7 trillion vehicle-miles of travel in the US, with automobiles being responsible for 64% of this travel. On the average each auto travels around 12,000 miles per year. Today's infrastructure was designed based on knowledge almost 50 years old.

The national infrastructure priorities include reducing delay and congestion, improving safety, reducing investment shortfalls, and getting longer performance of the built structures. The old 'same thinking' incremental approach will not meet 21st century highway needs. Reducing delay and congestion requires, of our structures, increased durability, extended service life, extended rehabilitation cycle, and elimination and/or minimization of work zone delays. Reducing investment shortfall can be achieved through improved decision making, optimizing resource allocations and reducing life-cycle costs. The goal of longer performance is achieving a 50 year pavement life and a 100 year bridge life.

The AASHTO has developed 'grand challenges' to address the growing infrastructure issues. These grand challenges outlined in its 'Strategic Plan for Bridges' (http://bridges.transportation.org) include:

- Extending service life
- Optimizing structural systems
- Accelerating bridge construction
- Advancing the AASHTO specifications
- Monitoring bridge condition
- Contributing to National policy and
- Managing knowledge

The FHWA's role in research and technology as also defined in TRB 261 report, The Federal Role in Highway Research and Technology (http://books.nap.edu/openbook.php?record_id=10222&page=1), include conducting long term, high risk, high payoff research, addressing emerging issues and technologies, delivery and deployment of technology, and providing national coordination and leadership.

Dr. Chase outlined a strategic approach with 4 core elements for an effective R&T program which he had developed while at FHWA. These include *information* for better decision making to support investment decisions and development of new technologies; *people* for an adequate and capable workforce with skills, knowledge and capabilities necessary to meet the challenges; *technology* leading to better knowledge and tools to design, construct, operate, preserve and manage the new and existing infrastructure; and *deployment* which puts it all together and into practice.

TRB Report 261 acknowledges that the FHWA's R&T program have a clear mission with well defined goals and complement other R&T programs. It also recognizes that total funding for Federal Highway R&T is low, and hence important research needs are not being addressed despite the potential for high payoff.

The 'barriers to innovation' also must be addressed in the highway industry. Many public sector agencies are averse to risk. A successful highway R&T program requires adequate and stable funding to achieve desired results.

The vision for the ‘bridges for the 21st Century’ is to get in front of the bridge deterioration curve and stay there. There are currently 160,000 bridges that are classified in the National Bridge Inventory as being deficient with over 3,000 bridges becoming deficient each year. Yet, over 1 billion users cross these deficient bridges each day. We are currently replacing or rehabilitating over 10,000 bridges per year at an annual cost of over $7 billion. The public demands increased mobility and less congestion, and resilient structures less vulnerable to hazards, both natural and human induced.

Highway structures need to be designed, constructed, and rehabilitated with standards and materials that provide longer and more reliable performance. They need to be constructed or rehabilitated with systems, methods, and practices that reduce congestion and improve safety. They need to provide a high level of safety and service under all conditions. They need to fit their environment. With these strategies in mind, Dr. Chase spoke of the three focus areas currently being implemented in FHWA’s R&D program. These include the Bridge of the Future initiative; the Stewardship and Management initiative; and the Bridge Safety, Reliability and Security initiative.

The Bridge of the Future initiative includes developing bridges with a 100-year life and minimal maintenance; constructed at a fraction of the current construction time and at a fraction of the current life cycle cost; adaptable for new demands; virtually immune to attack, floods, fire, earthquakes, overloads and other hazards; and with a total systems approach.

The Stewardship and Management initiative includes rapid strengthening, repair and restoration; maintenance and preservation technologies; filling knowledge gaps in deterioration science and control and better technology for condition assessment and diagnosis all for existing bridge population.

The Bridge Safety, Reliability and Security initiative includes addressing hazards such as earthquakes, scour, wind, collision, fire, floods, landslides, subsidence, overloads and attacks and developing bridges which are resilient to these hazards. It includes developing consistent and comprehensive approach to designing for and managing risk.

If things are to change then it is necessary to move beyond incremental improvements and encourage risk taking while assuring safety. Dr. Chase stated that the FHWA can help through programs such as the Innovative Bridge Research and Deployment program which was developed to encourage bridge owners to employ new technologies with the Government covering the delta cost.

In summary, as depicted in the figure 4, Dr. Chase emphasized that the strategic approach in achieving the goal to enhance bridge performance must include four aspects: information, people, technology and deployment.

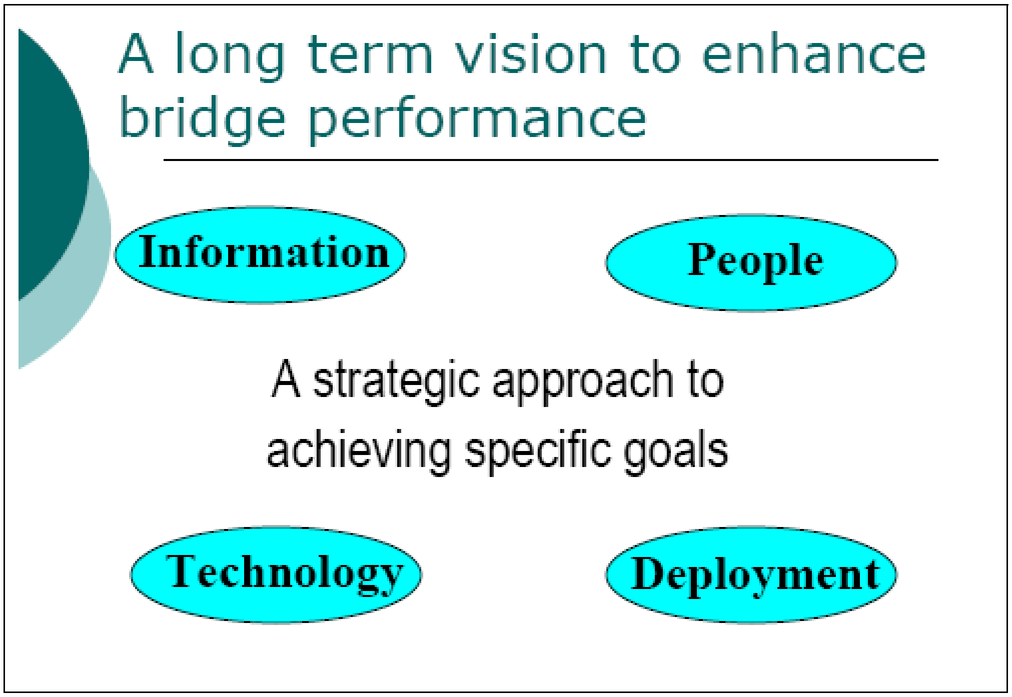

Figure 4 Core elements for an effective RD&T program

5.3 Technologies for Condition Assessment of Bridges

Glenn Washer, Ph.D., P.E., M. ASCE, Assistant Professor at the University of Missouri, gave a presentation on technologies for condition assessment of bridges. Dr. Washer's presentation included an introduction to Non-Destructive Evaluation (NDE); capabilities of visual inspection; electromagnetic methods; acoustic methods; future needs; and conclusion. Below is a summary of what was presented.

Non-Destructive Evaluation is a means of determining condition of a material without altering the material after examination. NDE methodologies basically use different frequency waves, transmitting these into a structural member being inspected. By analyzing its response, such as frequency, amplitude, time of flight, etc., as the waves travel through the material, flaws in the material can be determined.

Inspection utilizing NDE technologies can be advantageous, as it can detect deterioration at sub-critical levels, detect deterioration during embryonic stages, and provide quantitative knowledge on the condition of the subject being inspected. This can be used to an advantage to make maintenance decisions as it gives information to identify repair needs which focuses on criticality of the defect and/or deterioration, and which could lead to reduced cost of repairs.

The 'electromagnetic techniques' that are in use include dye penetrant, magnetic particle, eddy current, radiography, and magnetic flux leakage for steel structures; and ground penetrating radar, infrared thermography, and radiography for concrete structures. These technologies have the ability to detect even the smallest fatigue cracks, cracks in weldments, delamination, etc., such as shown in the figures 5 and 6.

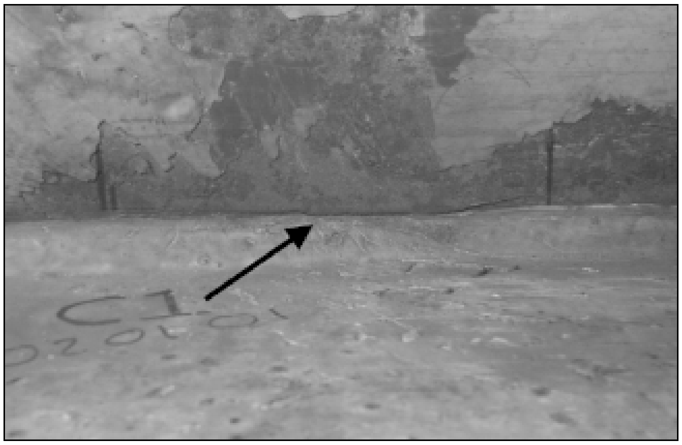

Figure 5 Longitudinal crack at weld toe

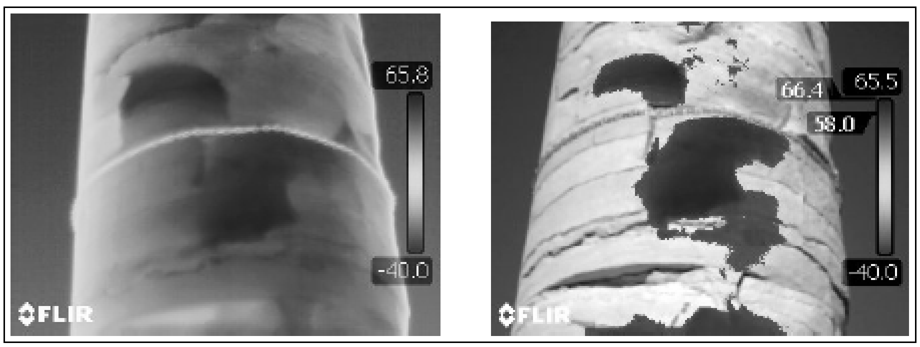

Figure 6 Thermal images of columns

The “acoustic methods” that are in use include chain dragging or hammer sounding, impact echo, seismic methods (such as the spectral-analysis-of-surface-waves method [SASW]), and ultrasonic pulse velocity for concrete structures; and ultrasonic and acoustic emission for steel structures, the type defined by the frequency of the acoustic wave used to transmitted the signal as shown in figure 7. Acoustic sensors can be used to detect crack growth, breakage in wires or any changes which alters acoustic signals.

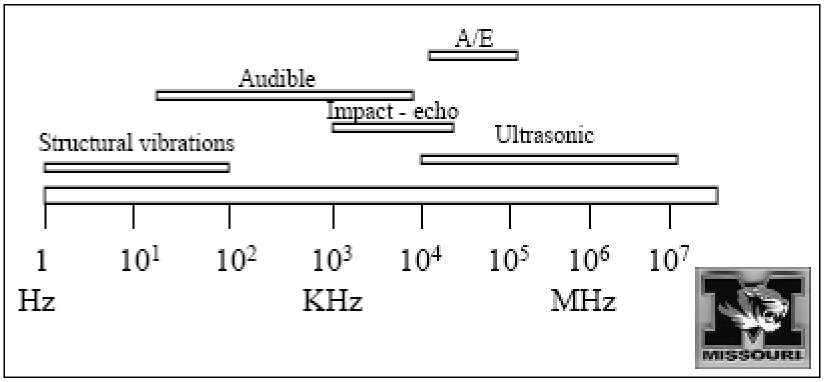

Figure 7 Acoustic methods for NDE

Dr. Washer described each of these techniques with examples of cracks or other defects detected using each technique.

Future challenges remain. These include being able to rapidly evaluate deterioration in concrete; detection of deterioration in prestressed, post tensioned and stayed cables; mitigating risk vs maintenance/condition assessment; and improvement in the reliability and quality in the science of inspection. Future needs include implementation of NDE within the inspection process, and development of risk based inspection procedures with reliability of methods and deterioration models.

5.4 Overview of the FHWA's Long-Term Bridge Performance Program

Hamid Ghasemi, Ph.D., Program Manager of FHWA's Long Term Bridge Performance Program, gave an overview of the program.

The National Bridge Inspection Program was created by Congress as a direct result of the Silver Bridge Collapse in Wheeling, West Virginia in 1967 which claimed 46 lives and 9 injuries. This was set up as a safety program collecting bridge condition and inspection information. The information collected has served as a basis for bridge research, analysis, decision making and funding apportionments for four decades. However, there is increasing awareness that additional factors may need to be examined to more closely determine bridge performance. Towards this end a new program was established under the current Highway Legislation, 'SAFETEA-LU'. The Long Term Bridge Performance (LTBP) Program is a 20 year program designed to study bridge performance issues.

The primary objective of the LTBP Program is to collect, document, maintain and make available high-quality, quantitative bridge performance data from representative bridge samples nationwide. The anticipated impact includes:

- Improved knowledge of bridge performance;
- Advances in deterioration and predictive models;

- Effective use of life-cycle cost analysis;
- Improved inspection/condition information through nondestructive evaluation and structural health monitoring;
- Help in fostering the next generation of bridge asset management systems;
- Deterioration models that can simulate interactions between pavement, bridges and traffic;
- Support for development of improved design methods and maintenance/bridge preservation practices;
- Foster technology for assessment of critical but invisible bridge elements and components; and
- Contribution to setting national policy.

Bridge performance is a key factor in determining the optimal operation of a highway system; however, there are gaps in knowledge due to data uncertainties and incomplete data. The National Bridge Inventory was not intended to be used for assessing bridge performance or how bridge performance impacts highway systems, yet this is how it is used. According to a survey conducted by the FHWA's Bridge Management Information Systems Laboratory in 1999, three States indicated 'sufficiency rating' (from NBI) was the only performance measure used; eight indicated they used 'number of deficiencies' as the performance measure; and another eight indicated they used both the sufficiency rating and the number of deficiencies as the primary 'performance measure'. Other measures used included the number of bridges needing work; structural deficiencies, posting or sufficiency rating; deficiencies and load carrying capacity; bridge in 'safe' condition as determined by the State's own formula; multiple ratings including sufficiency ratings and deficiencies; and customer satisfaction measures.

The shortfalls with current bridge inspection methodologies are that it is subjective, and gaps in knowledge of bridge deterioration, bridge performance and Life Cycle Cost analysis exists. There is uncertainty in measuring bridge performance as it is not well defined, understood or documented. It relies too heavily on expert opinion and not on objective data, and it is based on significant assumption or generalization based on very simplistic understanding of bridge behavior.

The LTBP program, while focusing on the most common bridge types, will on a representative sample of bridges conduct detailed inspection, periodic objective evaluation and monitoring over a 20 year period. Smaller sample of bridges will be continuously monitored. Further forensic autopsies of decommissioned bridges will be conducted. The detailed periodic inspection will yield high quality data which will be used to correlate changes in bridge condition and capacities. The LTBP program, however, is not intended to become a repository of vast amounts of bridge data without consideration of the value of the data in assessing bridge performance.

In order to ensure that needs of the stakeholders and partners are identified and considered, workshops have been held introducing the program and to acquire input from the owners and others with expertise in this area.

Some of the key points from FHWA's perspective are that today the bridge population is aging and yet the performance is poorly understood; currently available data will not support desired performance assessment; and it is hoped that the LTBP program will lead to better understanding for improving bridge performance.

Key points from the State DOT's perspective are that the available funds have leveled off; material prices are escalating; traffic volume and load demands are growing; user expectations are growing; and the need to eliminate deficient bridges exists. The LTBP program should help the State meet these challenges.

In summary the current bridge performance assessments are based on subjective data and generalization. The quantitative data and knowledge gained from the LTBP program could lead to better understanding of bridge performance; improved knowledge of bridge deficiencies; better design and construction methodologies; improvements in effectiveness of bridge inspection and management programs; and efficiency in the management of highway systems.

6. BRIDGE DETERIORATION ISSUES AND PERFORMANCE MEASURES

The Chairs of the ASCE/SEI bridge technical committees under the Bridge TAC or their representatives gave presentations on bridge deterioration issues and performance measures of concern within their committees' scope. Their presentations are summarized below. The question-and-answer session that followed the presentations is provided in Appendix F.

6.1 Steel Bridges

Reagan Herman, Ph.D., A.M. ASCE, Senior Lecturer and Assistant Research Professor at Johns Hopkins University and Chair of SEI's Steel Bridge Committee delivered the presentation on steel bridge deterioration issues. She provided information on the most common deterioration mechanisms affecting the steel bridge inventory and began discussion of actions needed to ensure acceptable performance of both current and future steel bridges.

Steel bridges constitute approximately 32% of the National Bridge Inventory. Eighteen percent of steel bridges are classified as functionally obsolete and 21% as structurally deficient. For steel bridges the most common sources of structural deficiency are two age related phenomena: corrosion and fatigue. Both the independent and combined effects of corrosion and fatigue are of concern across all elements of steel bridges, but are of particular concern in fracture critical members.

Corrosion of Steel Bridges
Corrosion can have a wide range of impact on steel bridges. On one end of the range are cases where there is actually no real effect on the steel superstructure, but unattractive staining of the bridge substructure. Such staining does not impair the safety or serviceability of a bridge, but can have a deleterious impact on bridge aesthetics and consequently public perception of the "quality" of the bridge. Thus light corrosion does impact transportation system performance in terms of the public's confidence in the civil infrastructure. At the other end of the range is severe corrosion where there is significant section loss, to the extreme where the original steel section is gone and there are holes or solely corrosion products in some portions of steel elements. Such cases will clearly be critical in terms of serviceability and often safety.

Corrosion inspections of the superstructures of steel bridges are inherently easier than concrete bridges given the fact that the steel elements are exposed. But there are many corrosion related concerns that are common to both steel and concrete bridges where the corroding steel is encased in concrete. These common concerns include corrosion, spalling, cracking, scour, etc. of the concrete decks and substructure elements of the bridges. Leaking at deck joints is also a concern that is common to both bridge types.

The two most common corrosion protection systems used in steel bridges are coatings/paints and weathering steel. There has been both good and poor performance with each of these systems. A significant reason for poor performance of weathering steels in certain bridges has been the lack of wet-dry cycles at the sites of these bridges. Wet-dry cycles are necessary to develop the protective patina of the weathering steel. Poor performance has also resulted in areas where weathering steel was improperly used at sites that have extreme marine conditions, include use of de-icing salts, or have heavy surrounding vegetation.

There have also been instances of poor performance for steel bridges utilizing coatings and paints. Catalysts for poor coating system performance include inadequate surface preparation and poor application techniques, as well as cases where the coating was simply a poor product. Specifying that a coating system be used is not enough: the coating must be properly applied and the coating must be robust enough to provide protection in the particular environment in which it is used.

Different steels and coating materials are being used in newer bridges and will be used in future bridges. It is felt that newer high performance weathering steels and coatings will provide heartier protection than the older systems. There has been significant interest in development of new single-coat, two-coat, and three-coat systems that can provide much longer service lives to enhance the performance of future bridges.

There is data collection that must be done to learn from the known corrosion problems with our existing steel bridge inventory. There is a need for much data including the location of problems and their root causes; the environments where systems with poor performance were used to help identify if problems are local concerns or issues that may be reoccurring; repairs that have been used; repairs that have worked; and the lifespan of good repairs. There is the well-know difficulty regarding differences in accelerated corrosion studies vs. real life in-situ performance. Our industry must utilize the ample in-situ data waiting to be collected from our steel bridge inventory. These data are needed to assist in our decision making processes for remediation of existing bridges and design of new bridges.

Fatigue and Fracture in Steel Bridges

Deterioration in steel bridges can also be tied to the effects of fatigue, and the potential for fracture in critical elements is a significant safety concern. One reasonable protocol for fatigue crack investigation would be to conduct remaining fatigue life analyses and use shop drawings to help identify details that are vulnerable to distortion. Suspect details can then be given special attention in inspections, thus focusing attention where it is most needed. Various flaws (including partial penetration, lack of fusion, porosity, inclusions, and undercutting) contribute to the likelihood for fatigue problems. Current fabrication practice should include reduction, and strive for elimination, of these errors.

The most common type of fatigue damage in U.S. bridges is web gap cracking. Past practice included a fear of welding to the tension flanges of steel girders which contributed to the proliferation of web gap cracking. The concerns with welding to the tension flange related to low quality steel used in past times, which is not an issue for newer bridges given the toughness requirements in newer steels. Current practice does require welding of transverse stiffeners to tension flanges for the transverse stiffeners that are attached to cross-frames or diaphragms. The transverse stiffeners attached to cross-frames are the ones that receive forces that promote distortion.

Though the details that led to web gap cracking are not used in newer bridges, there is a significant amount of steel bridge inventory that was designed using details susceptible to this cracking. There are tell-tale signs, such as bleeding at cracks, which can assist inspectors in identifying the cracks. But even without overt signs like bleeding inspectors must be aware that this detail is one that requires close attention.

When one fatigue crack is identified on a bridge there will almost always be others. Careful inspection and retrofit of the affected areas are critical. Various approaches have been used to address web gap cracking including drilling holes at tips of cracks and modifying the structural behavior of the system through retrofits. Opposing philosophies of retrofit designs exist with some approaches that reduce the driving force at the connection, others that reduce the flexibility at the connection, and still others that increase the flexibility at the connection. Data needs for all types of fatigue concerns include locations of the problem details and identification of the root causes; determination of whether a given problem is bridge specific or a global concern; creation of a database of repairs that have been used; assessment of which repairs have worked; and identification of any fatigue problems that are developing with new design details and/or new steels.

Deterioration and Redundancy

Discussions of deterioration in steel bridges naturally lead to the topic of redundancy, as deterioration in non-redundant systems is a critical safety concern. There is not clarity among the profession regarding which bridges/bridge elements are redundant and which aren't. There are also questions about whether redundancy can in fact be proven analytically, which has been attempted in some cases. Complicating this issue is the lack of consensus regarding which structural types/elements are fracture critical and which are not. There are very active dialogues in different focal groups on both redundancy and fracture critical. The results of these discussions will be critical in enhancing the performance of our steel bridges by identifying bridges/elements that need the most attention in inspections.

6.2 Timber Bridges

James Wacker, P.E., M. ASCE, Research Engineer with the Forest Service, Forest Products Laboratory and Chair of SEI's Timber Bridge Committee gave a presentation on timber bridge deterioration issues and performance measures. He provided an engineering perspective on key deterioration issues encountered on timber bridges across the entire spectrum of design, fabrication, construction, inspection, maintenance, and repair/strengthening. Looking to the future, potential performance measures were also outlined which could either enhance on-site inspection methods or support automated health monitoring systems over the long-term.

Approximately one in six highway bridges in the U.S. has been built using timber as a primary structural component. The National Bridge Inventory (NBI) includes approximately 30,000 all-timber superstructures and another 30,000 bridges made of timber decks on steel girders. There are many additional timber bridges with maximum span lengths less than the 20 ft required to be listed in the NBI. Typically timber bridges have a 10-60 ft span range and are located primarily along rural roads.

Timber has several distinct characteristics as a bridge material. It has a high strength-to-weight ratio which reduces the superstructure dead load. It also has good damping characteristics and hence can be overloaded for short durations, reducing the effects of vehicle impact loads. However, its long-term durability is predicated on limiting moisture-content related deterioration. Early American bridge builders realized that keeping their wood trusses dry by covering them with a roof structure significantly increased their durability without the use of chemical preservatives. The historic covered bridges that received proper maintenance and timely repairs have survived through the years in remarkably good shape, with some still in service for more than 100 years. Modern designers and builders of timber bridges should strive to achieve long-term durability of these historic covered bridges.

This discussion on timber bridge deterioration issues focused on widespread problems that can significantly reduce service life, rather than on isolated problems. When several of these issues are combined, they can significantly limit the service life of timber bridges.

Deterioration issues include over-reliance on preservation treatment, poor moisture and drainage details, insufficient inspection practices, inconsistent maintenance and repairs, and elevated moisture contents. The first deterioration issue is the over-reliance on preservative treatment as a primary means to obtain material durability. Current practice is to pressure-treat all bridge materials to generate a protective shell of treated wood, and then field-treat all cuts and bores which is a less effective protection method. Many avenues for moisture intrusion and early deterioration compromise the protective shell right from installation. Short-term solutions include not allowing drilling or boring, using alternative connection details, and saw-kerfing the underside to minimize checking (i.e., small cracks in the wood members). Long-term solutions include developing more durable protection measures such as encapsulation techniques using FRP composite products.

The next deterioration issue is poor moisture management and inadequate drainage details. Current practice to prevent ponding of precipitation is to use a waterproof membrane and crowned asphalt, and to place the bridge on a slight grade to facilitate drainage. In most cases, poor detaining near the edges of the bridge create moisture traps which prevent effective drainage and promote favorable conditions for decay. Possible solutions include development of more effective drainage detailing to keep the main structural members dry.

Insufficient inspection practices can also lead to deterioration if the initial stages of a problem are not detected. Visual techniques with some hammer-sounding are typical for routine inspections. Condition ratings tend to be unreliable, with high variability depending on inspectors who may be unfamiliar with timber bridge components and overly conservative. Possible solutions include measuring internal integrity, e.g., with stress-wave or resistance drilling; designing for inspection; and developing effective monitoring systems with sensors for early detection of problems and incorporating proven nondestructive inspection techniques.

In addition, inconsistent maintenance and repair can lead to deterioration. Currently routine maintenance is sporadic, and most repairs occur after significant decay. A new emphasis on more diligent maintenance practices and timely repairs is needed, along with a reprioritization of the funding process.

Elevated moisture contents continue to be a deterioration issue. The current practice is to specify 19 percent maximum moisture content for all bridge components at installation. However, compliance is poor due to lack of enforcement, drying effects, and cost. Post-treatment drying with water-based preservatives is also an issue. Conditions favorable for internal deterioration include the use of water-based treatments which add moisture into the wood and slow the drying process, as well as field cuts and borings that become highly susceptible to deterioration. Possible solutions include ensuring better quality control when wood products are fabricated and utilizing new drying techniques such as RF and microwave drying of larger bridge components.

The next discussion focused on what can be done to improve current inspection methods or propose new long-term monitoring concepts that will provide the basis for a health monitoring system. Several candidate NDE techniques could be evaluated for effectiveness at inspecting the internal condition of timber bridge components. For more continuous data on timber bridges, there are several components that would comprise a comprehensive long-term bridge monitoring program. The main components of the proposed monitoring system would include early decay detection, in-situ moisture levels, live load and deflection measurements, and modal testing techniques.

The current practice for measuring in-situ moisture contents conducive for decay is to use a hand-held electrical resistance probe and obtain localized data with three-inch probes. Embedded array sensors are needed that can trigger appropriate remedial action. A possible solution is wetness sensors at the topside of timber beams and caps that trigger appropriate repair action. Reliable sensors for measuring wood moisture are also needed.

The current practice for measuring deflection and strain under service live loads is to do a full-scale load test. The static load test is typically triggered by a low overall bridge rating and can be costly and time-consuming. Embedded sensors for target areas could estimate axle loads or pre-weighed vehicle and provide a burst of deflection/strain data. Fiber-optic and other technologies are a possibility. Costs for sensors and monitoring need to be evaluated as well.

Finally in-place vibration testing could measure system integrity. An automated control system could detect changes in vibration characteristics and has the potential for estimating overall stiffness and residual strength of the superstructure.

In summary, the main deterioration issues for timber bridges are the over-reliance on preservation treatment, poor moisture management and drainage, insufficient inspection practices, inconsistent maintenance and repairs, and elevated moisture content at installation. Correcting these deterioration issues will require a major shift in all aspects of design, construction, inspection, maintenance, and repairs. More emphasis by designers must be placed on long-term durability of the primary bridge components, including the adoption of life-cycle approaches. Proposed long-term performance indicators include early warning of internal decay or insect activity, moisture content levels conducive for decay, deflection and strain under service live loads, and vibration as a measure of system reliability. New and cost-effective technologies will be needed to fully implement a reliable long-term health monitoring system on a subset of timber bridges.

6.3 Concrete Bridges

Nur Yazdani, Ph.D. P.E., F. ASCE, Chairman of the Civil Engineering Department at the University of Texas at Arlington and **Danielle Kleinhans, Ph.D., P.E., M. ASCE**, Group Manager for Structural Engineering and Mechanics at CTLGroup, Chair and Secretary of the SEI's Subcommittee on Concrete Bridge Design (Joint with American Concrete Institute Committee 343), respectively, gave joint presentations on issues of concern with concrete bridges. Below is a summary of their presentations.

Deterioration Causes

Concrete bridge deterioration is one of the leading causes of highway structural deficiency, appearing mainly as either concrete distress or reinforcement corrosion. The types of deterioration generally appearing in concrete are scaling, spalling, cracking, abrasion damage, mortar flaking, alkali aggregate reactivity, delamination, freeze thaw, and sulphate attack.

Scaling is local flaking or peeling away of the near surface portion of hardened concrete. Common causes are poor air entrainment, improper finishing, deicing salts, and surface softening.

Spalling occurs when a segment of the concrete surface, frequently a rough circular or oval shape, is missing. Two common causes of spalling are corrosion of the reinforcement and improperly constructed or maintained joints. Without a doubt, surface spalling is the most serious and troublesome type of bridge deck distress.

Cracking many times occurs in new concrete and worsens over time, while in other cases cracking forms after the concrete has matured and the structure is open to traffic for some time. Some of the most common types of cracks are plastic shrinkage cracks, drying shrinkage cracks, settlement or subsidence cracks, temperature-induced cracks, flexural cracks, and shear cracks.

- Plastic shrinkage cracks form in the deck when the evaporation rate exceeds the bleed rate of newly placed plastic concrete. Extreme environmental conditions and high concrete temperatures increase the surface evaporation rate and thus increase the deck vulnerability to plastic shrinkage cracks.

- Settlement or subsidence cracks form over and parallel to the top-most reinforcement as the concrete settles around the bars as it dries.

- Temperature-induced cracks are caused when unrestrained concrete undergoes volumetric changes as it experiences temperature variations. The mechanism that causes thermal cracks in decks is very similar to that which causes drying shrinkage cracks.

- Flexural cracks can form when the concrete is in its initial maturing stage just after placement as well as in service. If unshored, concrete in its plastic stage can develop flexural cracks in the negative moment regions over the interior supports of continuous spans due to the dead weight of the girders plus the newly placed concrete. When the deck is in service, the addition of live loads can also cause cracking in the negative moment regions. Furthermore, gravity loading can cause under-deck cracking in the positive moment regions of both simply supported and continuous spans.

Abrasion damage in wheel tracks can be caused by studded tires and chain wear. Such damage can also be caused by the blades of snow ploughs. In addition, abrasion damage manifests itself as polishing of the aggregates which can lead to a slippery surface.

Mortar flaking occurs due to loss of surface mortar from above the top side of near-surface aggregate particles due to prolonged finishing of thin surface mortar over the top side of near-surface aggregate particles or inadequate curing.

Alkali aggregate reactivity may appear as alkali silica reactions (ASR), which occur when the reactive silica in the aggregate combines with cement alkalis to form a gel that expands and cracks the concrete. Alkali carbonate reactions (ACR) occur when the dolomite in reactive carbonate rocks combines with cement alkalis to form calcite and brucite. The result is expansion by moisture absorption of clay in the rock or the insitu formation of calcite/brucite, with resulting expansion and cracking.

Delamination is the separation of a horizontal plane of concrete, analogous to a skin blister, that usually occurs at or just above the top reinforcement in the deck. Common causes for delamination are air entrainment in concrete which will receive a hard machine trowel finish; premature finishing before the cessation of bleeding; prolonged finishing; factors that increase bleeding duration, rate and capacity; surface crusting, top-down stiffening, premature finishing; corrosion of reinforcing steel in concrete, and cyclic freezing.

Being alkaline in nature, exposure of concrete to acidic solutions causes loss of mass and loss of concrete strength. An example is the corrosion of column bases exposed to acidic solution.

In summary, many components and processes make concrete bridges highly susceptible to deterioration. Good quality control in the beginning, together with adequate maintenance and inspection, will help in deterioration control.

Performance Measures

Concrete can deteriorate due to many causes, including cracking, scaling, delamination, spalling, chloride contamination, efflorescence, ettringite formation, honeycombs, pop-outs, wear, collision damage, abrasion, overload damage, reinforcing steel corrosion, and prestressed concrete deterioration. Direct performance measures for concrete include load distribution factors, load impact factors, deflection, and strain/stress.

The potential deficiencies of these direct performance measures include the subjective nature of condition ratings, e.g., per Phares et al., 2004, 95 percent of primary element condition ratings for individual bridge components will vary within two rating points of the average, and 68 percent will vary within one point. Also, unknown conditions may exist because of the lack of "internal" inspections using Non-Destructive Testing (NDT), e.g., in post-tensioned grouted ducts.

Other potential deficiencies include the lack of quantitative data, the disconnect between inspection information and rating calculations, and the cause of distress not always assessed correctly, which can be evidenced by repeated failed repairs. Currently spalled areas and flange thicknesses are not measured routinely in bridge inspections, and this can affect the ratings calculations.

6.4 Bridge Management, Inspection and Rehabilitation

Sreenivas Alampalli, Ph.D., P.E., F. ASCE, Director of the Bridge Evaluation Services Bureau for the New York State DOT and Chair of SEI's Bridge Management, Inspection and Rehabilitation Committee, gave a presentation on national bridge inspections. His presentation first dealt with the evolution of national bridge inspection practices and standards, followed by the status of current bridge inspection programs as mandated by the Federal Highway Administration and reasons for inspecting bridges. He ended the presentation with his views on critical issues related to the national bridge inspection standards and possible future improvements.

Following the Silver Bridge collapse in 1967, an Act of Congress in 1970 first established the National Bridge Inspection Standards (NBIS) in 1971 to improve bridge safety. These standards have been modified several times, as recently as 2004, to reflect lessons learned from bridge failures and changes in the state-of-the-practice. The main purpose for these standards is to establish a national bridge inspection program to improve bridge safety, and establish a national bridge inventory of all highway bridges on public roads. The information gathered from bridge inspections is used to make decisions on bridge funding, etc. at a national level. The current program serves, in general, the Nation well.

Several issues were noted with the current NBIS with respect to making better bridge management decisions. These standards were created for routine bridges and do not adequately address special and complex bridges. The inspection information gathered also relies mostly on visual inspections that may not give adequate details on bridges with concealed elements. At the same time, no rational basis exists for current inspection intervals. The National Bridge Inventory (NBI) data itself also may not be enough for individual bridge owners, and hence, most owners collect information beyond what is required by NBIS to make appropriate planning, preservation, rehabilitation, and replacement decisions, i.e. bridge management decisions.

Possible improvements suggested include: a) accounting for the structure type and complexity in defining inspection intervals, personnel qualifications, data collection during inspections, etc. b) obtaining better consistency and uniformity in ratings collected as part of the NBIS inspections through better training, better manuals, QA/QC procedures, introduction of reference bridges, etc., c) pro-active inspections by collecting the data based on decisions to be made and risks to various hazards to which the structures are subjected, and d) leveraging new technologies and practices, when needed.

Finally, it was emphasized that safety aspects cannot be forgotten while improvements are made for collecting better data for bridge management purposes. Decision making processes should govern any changes made to the inspection program in the future, including introduction of new technologies and health monitoring.

6.5 Cable Supported Bridges

Khaled Mahmoud, Ph.D., P.E., M. ASCE, President of Bridge Technology Consulting (BTC) and Chair of SEI's Cable Supported Bridges Committee, gave the presentation on cable-supported bridge deterioration issues and performance measures. Cable-supported bridge deterioration issues relate to high-strength steel wire vulnerabilities, cable protection and inspection, and stages of corrosion and visual assessment. Performance measures include probabilistic evaluation of test data, assessment of the remaining service life of cables, and cable corrosion monitoring.

The basic component of a cable is the high-strength steel wire. While longer spans can be achieved due to the high-strength wires, a reduction in ductility (strain capacity) also results. Ultimate strain is an essential parameter and should be included in the evaluation of cable strength. For high-strength wire, the ultimate strain is less than six percent, compared to 24 percent for normal-strength wire. High-strength wire is brittle, and hence most wire breaks are brittle breaks. However, an inherent characteristic of a good wire is adequate elongation and strength, and therefore the wire should not have cracking problems. When the wires are spliced together, the stresses in the spliced wire are never quite the same.

Several strength models have been developed over the last few years for the strength evaluation of bridge cables. Most of these models rely on visual assessment of wire condition determined during inspection and do not provide a convincing cable failure mechanism. Additionally, the assessment of the cable strength is evaluated based on the wire ultimate strength, with little regard to the wire ultimate strain. Although, the wide variation observed in the ultimate strain of degraded wires requires that the strain data be included in the assessment model parameters.

Numerous test data from suspension bridges point to a wide variability in the ultimate strain data. That variability, which reflects on the ductility limit of the wire, has been traditionally ignored. Due to the large scatter observed in the ultimate strain data, a probabilistic-based analysis is recommended to address the variability and its effect on the cable strength. It should be noted that the degradation process affects the properties of the bridge wire. The variability noted here basically addresses the scatter observed in the measured properties of degraded wires. The safety appraisal of suspension bridge cables requires a thorough understanding of the cable failure mode and the degraded wire properties. It is equally important to establish the mechanism through which these parameters interact among each other, resulting in a lower capacity of the bridge cable strength. With this understanding, different level of safety, or in other words "reliability", of the cable could be defined. The ultimate goal is to arrive at an evaluation of the structural integrity that determines the margin of safety of the cable with a certain degree of reliability.

Much environmental degradation has surfaced in the last two decades. While less than 10 percent of cables are inspected and less than one percent are tested, cable inspections often reveal surprising corrosion. Forms of wire vulnerabilities and degradation include corrosion pitting, corrosion fatigue, stress corrosion cracking, and hydrogen embrittlement. In hydrogen embrittlement, necking is not seen. Visual inspections have also revealed water pouring from anchorages.

There are four visual stages of cable corrosion, with Stage IV being the most corroded. In Stage I, the zinc coating on the wires is oxidized to form zinc hydroxide, known as “white rust.” In Stage II, the wire cross-section is completely covered by white rust. In Stage III, ferrous corrosion due to the broken zinc coating is visible on 20 to 30 percent of the wire surface area. In Stage IV, the wire cross-section is completely covered with ferrous corrosion. Visual assessment can, however, be misleading.

A corrosion protection system for cables includes the galvanized wire with paste coating and round wrapping wire covered with a protective coating on the exterior.

Performance measures include acoustic and corrosion monitoring systems. Acoustic monitoring provides information on wire breaks. Corrosion monitoring provides information on the degradation of the wire. Each component provides an integral part of the overall cable health monitoring plan.

6.6 Bridge Security

James Ray, P.E., M. ASCE, Research Structural Engineer with the Army Corps of Engineers, and Chair of SEI's Bridge Security Committee, gave the presentation on bridge deterioration issues and performance measures from the bridge security standpoint. First discussed were terrorist threats against bridges and then a general mitigation approach. The presentation concluded with questions that were to be addressed in the bridge security breakout session.

Bridges have many threats, including overload, wind, scour, corrosion, earthquake, fatigue, vehicular impact, storm surge, and fire. After 9-11 the threat of terrorism was added to the list. Bridge security became such a new and hot issue that it was considered more than "just another threat." Fortunately, time is showing that it is in fact another infrequently-occurring but high-impact threat, much like all the others.

Bridges are attractive terrorist targets due to their economic importance to traffic and commerce, the fact that they support conduits for energy pipelines and telecommunication cables, their symbolism, the cost and time impact of replacement, the anticipated public impact from an attack, and the relatively high vulnerability (susceptibility and structurally). Accidents such as the April 2007 San Francisco/Oakland Bay Bridge ramp fire, and the August 2007 I-35W Minnesota bridge collapse show the vulnerability of bridges. Terrorists are aware of these vulnerabilities. The 1993 World Trade Center bombers also had a plot to detonate bombs in the Lincoln and Holland Tunnels and on the George Washington Bridge. In 2003 an Al-Qaeda terrorist was captured in New York; among his projects was developing a plan to cut the main cables of the Brooklyn Bridge.

Issues presented by terrorists and of importance to bridge security include (1) deliberate fire underneath superstructures and adjacent to piers; adjacent to towers, cables, arch ribs, and truss members; and prospect of traffic jams to limit fire fighter access, (2) deliberate impact via trucks, barges, ships, and planes to piers in water and on land, truss end posts, and arch ribs, (3) hand-carried cutting devices such as saws, grinders, cable cutters, and torches, and (4) explosion.

While explosion is not the only threat to bridges, it seems to be the terrorists' predominant weapon of choice. Vehicle bombs directly adjacent to critical members can be a concern as well as hand-emplaced explosives on critical members

A blast mitigation approach for low-risk bridges is (1) to develop an accelerated response and recovery plan and (2) to deter and deny. A mitigation approach for high-risk bridges is (1) to deter, deny, and detect, (2) to defend with standoff, and (3) to defend with structural hardening, the most expensive option; these three approaches are interdependent. “Deter” means that others know that they are being watched. This can be done by visible security measures, routine patrols, adequate lighting, and reduced hiding areas. “Deny” means preventing access by locked doors, fencing, and area control. “Detect” means electronic security, including closed-circuit television, intrusion alarms, and climb sensors.

Importantly, bridge monitoring technologies such as strain gauges, deflection monitors, and load sensors that are used for other reasons can also improve bridge security. Sensing technology uses include damage evaluation, determining the safety of structures for emergency operations, determining the residual capacity of heavily damaged structures, assisting in repair procedures and processes, and determining material performance.

Deterring, denying, and detecting will help limit the amount of time on target and initiate a response. Limiting the amount of time on target will reduce the number of threats. If undetected, any denial and hardening measures can be eventually compromised. If the deter-deny-detect tactics don’t work, then “defend” must occur with standoff or with structural hardening. Defending with standoff, which is relatively inexpensive, can be through the use of barriers such as railings and fences to protect critical bridge elements, including the use of dolphins, fenders, and caissons to protect piers in water. Structural hardening should be considered when sufficient standoff cannot be obtained or is cost prohibitive. Hardening should not affect the normal performance of the bridge. An example of effective hardening for blast loads is column wrapping, a technology already being used to increase the seismic resistance of bridge columns.

The questions to be discussed in the breakout session were:

- Seven years later, is bridge security still an issue?
- Can evolving bridge maintenance/monitoring technologies help mitigate terrorist threats?
- Can better bridge management help?
- Potential performance issues caused by bridge security?

7. CHARGE TO BREAKOUT SESSION TEAMS

The workshop participants were given their charge prior to them assembling in their breakout committee sessions. When discussing issues, the participants were asked to consider bridges to mean the whole bridge system including the superstructure and the substructure. We wanted to know the "what, where, and when," i.e.,

- Is the information we are gathering today adequate to determine the condition of our bridges and if not, what more is needed?
- What information on performance do we need which we are not getting now?
- How can more accurate conditions be determined?
- Do we have the technology to gather this information?
- Although there are commonalities, each bridge is different based on material type and design.
- Recent advances in high performance materials have made the use of these materials more common. There may be certain issues or aspects/data that need to be gathered to determine performance which is not being done today because it has not been necessary with traditional materials.
- Extreme events such as natural disasters and terrorism highlight the need for resiliency in our infrastructure. What information would help both before, during and after an extreme event or extreme loading condition?

In addition to considering the above questions, each breakout session team was asked to cover the issues listed below during their discussions.

Bridge Design

- What can be expected from the bridges we design today.
- The best practices in design and detailing that could be used to improve durability, extend service life and prevent premature deterioration.
- Building resiliency into the bridges, what the design and detailing challenges are for extreme events.

Performance Measures

- Bridge deterioration issues for your bridge type.
- The processes which reduce the life of a structure and the most effective existing and most promising preservation methods.
- Critical deficiencies in the type of data that is currently collected in standard bridge inspection/management practices.

- Whether the information we are gathering today is adequate to determine the condition of our bridges and if not what more is needed.
- How can more accurate conditions be determined?
- What information on performance is needed which we are not getting now?
- What information should be collected from which structural components to characterize the condition or health of the structure?
- The data needs for long term performance monitoring.
- What information would help both before, during and after an extreme event or extreme loading condition?
- Recent advances in high performance materials have made the use of these materials more common. Are there certain issues or aspects/data that needs to be gathered to determine performance which is not being done today because it has not been necessary with traditional materials?

Technologies to Monitor Bridge Life and Assess Condition

- The current and upcoming sensors and sensing systems, nondestructive evaluation tools, and reliable load rating methodologies that can be used to collect relevant quantitative data that determines condition and performance of the bridges for your bridge type.
    - Sensors for collecting data from damage
    - Sensors for collecting data from performance
    - Sensors for collecting data leading to better designs
    - Sensors for revealing construction and repair damage
    - Sensors for early warning
    - Sensors for damage evaluation
- Whether we have the technology to gather the information necessary.

Improvements in Decision Making

- How decision making can be improved through this comprehensive collection and evaluation of bridge performance and operations data.

8. BREAKOUT SESSION TEAM REPORTS

The afternoon of day two, the breakout session team chairs gave presentations on their breakout team discussions. Following the Workshop each team prepared a more detailed summary of the discussions, presented below. The question-and-answer session that followed each of their presentations during the Workshop is provided in Appendix F.

Figure 8 Bridge technical committee chairs and breakout team leaders respond to questions following their breakout reports

8.1 Steel Bridges

Steel bridges form an essential component of our transportation system. Steel is employed in many situations where it would be difficult, if not impossible, to traverse a crossing with another bridge type. Steel plate and box girders with long, curved spans are common in urban areas where they provide a means for vehicles to travel between major roadways without requiring movement through at-grade intersections. Steel arch and truss bridge types have been utilized in many applications crossing both minor and major rivers. The somewhat typical positioning of steel bridges along the body of, and in connections between, major thoroughfares clearly reveals the criticality of steel bridges to the flow of traffic at both local and national levels. Therefore measures to enhance the performance of steel bridges can provide significant benefit to the overall workings of our transportation system.

The topics discussed in the steel bridges breakout session are presented in two areas of this report: the following sections highlight critical concerns that were discussed at length in the session and the notes in Appendix E provide a full inventory of all topics of discussion.

Overview of Breakout Discussion and Data Needs

The two prime deterioration issues for steel bridges are corrosion and fatigue. For both corrosion and fatigue the breakout session members discussed root causes, impacts on safety and serviceability, methods of detection, reliability of detection methods, methods to delay or stop progression, data to be collected during inspection, assessment needs for collected data, and methods to improve performance in future bridges.

Corrosion

The main factors that promote corrosion in steel bridges were identified as joint leaks and poor details. Much discussion was focused on leaky joints and the common situation where there is heavy corrosion of five to ten feet of girder length under the joints, and little to no corrosion in other areas. The impact of joint problems is wide reaching given the fact that poor performance of joints also affects other bridge types.

The extensive problems with inappropriate installation of joints were discussed as was the need for intense inspection during joint installation. To improve performance in existing bridges there must be appropriate response to joints that are not performing properly and a focus on inspection and maintenance of all joints. It is also imperative that data on the condition of in-situ joints be collected, reduced, and disseminated nationally. Information on joint repairs that have been used and the performance of these repairs must also be collected and analyzed. Joints should be listed as an inspection priority and the inaugural inspection cycle for bridges, including the joint areas, should be performed before construction acceptance. Having a regular bridge inspection required before the bridge is considered complete should help assist quality assistance measures. The notion of joint and bridge warranties were also discussed as ways to encourage quality control.

Joint improvement would eliminate the root cause for a large percentage of corrosion problems. It was felt that the economic benefits of joint area repairs/retrofits could be easily demonstrated by mining inventory data to show the number of bridges that would be raised from deficient to adequate through joint area repairs.

Poor details are another factor that also has a causative relationship with corrosion. Problem details include those that promotes accumulation debris, including details that facilitate roosting of birds on the bridge. Data on poor details that are identified during inspection need to be collected, and suspect details should be identified. Inspectors should participate in continuing education throughout their careers and items like poor corrosion details should be highlighted during inspector training. Information on unsatisfactory details must also be included in designer life-long learning to eliminate use of such details in new designs.

Fatigue and Fracture

The common occurrence of overloads was discussed and the impact these frequent overloads may have on the fatigue life of steel bridges is a concern. The overloads will impact both stress induced fatigue, which can be predicted reasonably well, and distortion induced fatigue, for which our prediction techniques are lacking. Current design practice includes a philosophy of limiting distortion to remove the driving force for distortion induced fatigue. But details in older bridges that have susceptibility to distortion induced problems, like web gap cracking, must be focal areas in inspections.

Needed data with respect to fatigue includes inventories of observed fatigue crack locations, assessment of problem details, repair procedures and retrofits, and success/failure rates of retrofits. As with corrosion, ongoing education efforts for both inspectors and designers must include identification of problem details as well as better details for use in new design.

Technologies for Monitoring Bridges

Technological needs for steel bridges include advances in moisture, corrosion, and fatigue sensors. For fatigue, there is a need for sensors that measure actual stress, not simply changes in stress. Visual inspection can identify many problems like joint leaks, advanced corrosion, and propagating fatigue cracks, but sensors that can call attention to these problems as quickly as possible should provide opportunities for easier and more successful repairs. Corrosion and fatigue damage of fracture critical and non-redundant members were of particular concern in the discussion.

There is also a need for high-precision, rapid-operating surveying equipment for use in bridge inspections. A key performance measure for steel bridges is deflection, and the importance of deflection will only increase as new materials are developed and lighter bridge sections are used. A good goal is development of self contained loading vehicles that can perform near traffic speed load testing and immediate collection of deflection data.

Given the high cost of bridge instrumentations and the limited budgetary resources, allocation of attention and money to critical bridges and critical elements of steel bridges is the only logical approach to field monitoring.

Inspection, Response to Inspection Results, and Maintenance

Two global measures that can be used to assess performance are safety and serviceability, and bridge inspections must provide attention to both of these measures. But there needs to be recognition that safety is of prime importance when processing the results of the inspections. It is important to our industry that the public understand that assessment of a bridge as “structurally deficient” does not mean it is unsafe. However, we must ensure our inspectors are educated to recognize items that are in fact unsafe and make sure there is an immediate, extreme reaction in such cases.

The dissociation of inspection and maintenance must be eliminated. Toll authorities serve as a model example for this where, for example, a bridge is inspected and a leaky joint is found and then the next day maintenance is out working on this joint. The fact that maintenance is key must be appreciated at all levels. When considering the full bridge inventory, money spent on maintenance most assuredly is money that is very well spent.

Bridge Design

Findings from data collected from the current bridge inventory must be used to improve future designs. There is a physical separation between design, construction, inspection, maintenance, and research because most people work in only one of these areas. Therefore the “back and forth” transfers of information that are needed between each and every one of these five groups is in many cases not happening. For example, the design group must have active feedback from the inspection group so that designers can rapidly eliminate the identified problem details from new designs. And the construction group needs to have active feedback from the maintenance group to learn when construction techniques that are not expressly specified, but are instead “typical practice,” are actually causing maintenance problems later in the life of the bridge. An administrative infrastructure is needed that fosters communication between each and every group. This communication will help move the industry to being proactive rather than reactive in terms of enhancing bridge performance.

8.2 Timber Bridges

Timber bridges provide an economical and durable alternative for short-span crossings (<50ft) along many secondary rural roadways in the U.S. While new bridge construction numbers are decreasing, a sizable inventory of timber bridges (~30,000 nationwide) exists in the National Bridge Inventory. Therefore, the most urgent need is to develop strategic maintenance practices and more cost-effective means of repair & rehabilitation in order to extend service lives of the existing bridges.

Several deterioration and performance-related issues prevent most timber bridges from fully achieving their service life potential. Across the entire spectrum of design – fabrication – construction, we need to better educate practicing engineers about the nuances of timber as a bridge material. This will include best practice manuals, focused training modules, user-friendly design tools, and updated and expanded information in the codes and standards.

Specific performance measures discussed included data on early decay detection, in-situ moisture content, and live load strain distribution. However, many of these will require significant research and development to meet the stringent requirements of the sensors (ruggedness, low cost, low power, wireless, miniature, embeddable, high signal/noise ratio, etc.) needed for reliable long-term bridge monitoring.

New techniques are needed to more reliably evaluate the condition and performance of timber bridges. Integrating existing NDE technologies may assist inspecting engineers gain a better understanding of the internal signs of deterioration, while exploring the adaptability of non-traditional (for wood materials) NDE technologies to timber bridge components could yield positive results. There is also a need for improved education of bridge inspectors and engineer's who determine safe load capacities for timber bridges, typically their least familiar bridge material.

Improvements in all listed areas will support improved decision making in the management of timber bridges. Designers will provide more long-term durability detailing into their initial designs and rehabilitation efforts. Inspectors will recognize critical signs of deterioration or damage earlier to support timely repairs or traffic restrictions. Load rating engineers will calculate safe load carrying capacity with more confidence. The cumulative effect of these singular actions should be the transition towards a more comprehensive design process that fosters more of a life-cycle approach for timber bridges of the future.

Overview of the Breakout Discussion

The group discussion was focused on the following topical areas: bridge design, performance measures, technologies to monitor or assess condition, and improvements to decision making.

Bridge Design

Limited education and knowledge by engineers about timber bridges (extending across the design-fabrication-construction spectrum) is a major factor which leads to poor bridge performance and reduced service lives. Only a few universities in the U.S. offer timber-material or timber-structure courses which leads to limited understanding of timber as a structural material. In addition, it was noted by consulting engineer participants that on-the-job training for timber bridges is becoming less common today as well. The combined effects are that construction of new timber bridges is decreasing due to this unfamiliarity as a bridge material and many of those recently constructed don't employ proper structural and durability detailing.

The following suggestions were offered:

- Generate a Best Practices Manual to guide engineers thru the entire spectrum of design, fabrication, and construction which includes design details.
- Conduct focused & comprehensive training module for timber as a bridge material.
- Work towards inclusion of timber structures in more college curriculums.

Performance Measures

Specific performance measures included data on early decay detection, in-situ moisture content, and live load strain distribution. Many of these will require significant research and development to meet the stringent requirements of the sensors (ruggedness, low cost, low power, wireless, miniature, embeddable, high signal/noise ratio, etc.) needed for reliable long-term bridge monitoring.

The following suggestions were offered:

- Early decay detection (via chemical test kit) could be integrated into the routine inspection whenever drilling or boring occurs.
- Further development is needed of embeddable sensors or remote sensing devices that can more effectively characterize the moisture contents in bridge members.
- Fiber optic sensors are currently being evaluated for effectiveness as embedded sensors in new glulam bridge beams, but it is too early to determine their effectiveness in bridges.

Technologies to 'Monitor or Assess' Condition

New techniques are needed to more reliably evaluate the condition and performance of timber bridges. Integrating existing NDE technologies into routine inspections may assist inspecting engineers gain a better understanding internal signs of deterioration, while exploring the adaptability of other non-traditional NDE technologies to timber bridge components could yield further benefits.

The following suggestions were offered:

- Provide inspector training module that focuses solely on timber bridges.
- Get economical NDE inspection tools at the local level and provide training.
- Ground penetrating radar, x-ray tomography are a few NDE technologies that may be adaptable for inspecting timber bridges.

Improvements in Decision Making

We identified several areas that need improvement in decision making. We felt that most engineers are least familiar with timber as a bridge material and that leads towards mistakes or overly conservative decisions. The following summarizes our discussions:

Routine Inspection

- Inspectors need to easily recognize visible signs of deterioration; we proposed the development of handy field manual, or possibly software module adaptable for handheld;
- Key deterioration or serviceability issues vary based on superstructure type. A guidance manual would aid bridge inspectors in performing task;

Maintenance

- Bridge owners need improved rationales for performing routine maintenance and remedial actions in a more cost-benefit approach;
- One idea was to develop a specific timber bridge owners' manual that lists specific maintenance practices with desired intervals for maximizing the life of your bridge.

Load Rating

- The supplemental data from NDE tool incorporation into routine inspection process should allow for improved condition ratings; In addition, more guidance is needed through the unfamiliar territory of the 'Timber Structural Load Rating Process'.

Bridge Closures

- Inspectors need to be aware of those critical conditions and/or deficiencies in timber bridges that pose a significant safety risk and warrant an immediate bridge closure. A guidance manual with examples and photos was suggested and could easily be incorporated with inspection tools described previously.

Other Issues

- A majority of discussions pertained to superstructure issues, while the group fully recognized the importance of substructure towards the overall bridge performance. Future workshops should place more emphasis on substructure deterioration and performance issues.
- Future research should focus on the maintenance, inspection, and repair methodologies for extending the service lives of the existing bridge inventory.
- Serviceability issues are also an important consideration for timber bridges. The difficulty timber bridges exhibit with problematic asphalt wearing surfaces on flexible deck systems is one example. These can be critical factors affecting the engineering perception of timber bridges.

8.3 Concrete Bridges

Concrete bridges are playing vital roles worldwide in transportation networking, both in major and minor bridge applications. A variety of bridge types, span lengths, orientations and aesthetically pleasing and durable applications can be achieved economically through the application of concrete. Three major issues related to concrete bridges were considered: (1) bridge deterioration issues; (2) bridge monitoring and condition assessment technologies; and (3) improved decision making. The issues apply to all four major bridge components; i.e. deck, superstructure, substructure and the foundation.

Various parameters may be used to define the performance measures of concrete bridges. Many of the concrete bridge deteriorations that take place are caused by inadequate construction practices, concrete production and finishing techniques. Proper quality assurance and quality control is needed also in material selection. Better communication and coordination among designers/contractors, maintenance personnel and professional organizations is vital to improve performance of bridges. Also needed is better record-keeping, better understanding of what methods work and successful overseas experiences.

The bridge design process must address performance needs and future repairs/inspections. Well-known measures may be taken to extend service lives of concrete bridges and resiliency against extreme events. Other important issues for consideration are scour, rapid construction techniques, and new/emerging materials. Qualified bridge inspectors should be retained and developed, together with innovative inspection techniques.

Proper quality control for concrete bridges is essential. This may include contract documents enforcement, proper training of personnel and the utilization of performance-based specifications and value engineering. Excellent technologies for bridge monitoring are available for various circumstances, monitoring time period, event triggered and economics based.

Due to the critical nature of the concrete bridge deterioration nationwide, it has to be itemized as a national priority. Emergency policy steps are needed to address this critical issue.

Overview of the Breakout Discussion

The purpose of the Concrete Bridge Breakout Sessions was to discuss the following issues as they relate to concrete bridges:

- Bridge deterioration issues and critical deficiencies in the type of data currently collected in standard bridge inspection/management practices.

- Technologies that could be used to monitor bridge life and assess condition.
- Improving decision making though comprehensive collection and evaluation of bridge performance data.

These issues need to be looked at for all of the main components of a bridge, such as the deck, superstructure, substructure, and foundation.

Figure 9 Concrete 2 breakout team discusses the issues

Performance Measures

The current practices need to be reviewed in order to be able to quantify performance based upon objective, relevant data. The performance of a concrete bridge can be measured in relation to each of the following parameters:

- Durability
- Best practices
- Strength (safety)
- Serviceability
- Prevention of deterioration
- Preservation methods
- Critical deficiencies in data collected
- Vulnerabilities/Security
- Operational efficiency
- Resiliency against extreme events
- Extended service life

Prevention of Deterioration

Various types of concrete bridge deteriorations were covered in the ACI-SEI Committee 343 presentations at the workshop. Such deterioration may include: scaling, cracking, spalling, popouts, delamination, mortar flaking, abrasion damage, alkali-aggregate reactivity and corrosion of reinforcement. Many of these deteriorations are caused by inadequate concrete production and finishing techniques, and also due to inadequate construction practices not conforming to various applicable codes of practice. Corrosion of steel reinforcement is a major contributor to concrete bridge deterioration. Proper quality assurance/quality control (QA/QC) is needed in the material selection process as well.

Some of the critical deficiencies in data collected from concrete bridges are listed in the following:

- Load information (Overloads permitted)
- Overloads linked to deterioration – research needs to be conducted to correlate deterioration and overloads
- Take bridge measurement issues more seriously (take action on inspection recommendations)
- Qualifications of inspectors (discussed later on)

Coordination and Communication

Communication and sharing of experience is the key to improving bridge performance. In particular, communication between the following entities is highly desirable:

- Designers and Contractors
- Maintenance Personnel and Designers
- Professional Organizations (ASCE, American Concrete Institute [ACI], Precast/Prestressed Concrete Institute [PCI], American Association of State Highway and Transportation Officials [AASHTO], etc)

Better record keeping is needed so that the bridge deterioration process can be better understood. A national database should be created to store this information. The potential exists to link Pontis and the NBI to assess the impact of repairs/improvements and their deterioration over time. The root cause of the issue needs to be identified in each case in order to properly assess and repair the structure. A better understanding of the maintenance, rehabilitation, and repair measures that are working and not working can be achieved through this communication. We must also look at what is being done in other countries and draw upon their experience and incorporate this knowledge into our practices.

Concrete Bridge Design

The bridge design process must match design criteria to actual performance requirements. The design should facilitate future repairs and inspections. For example, the designer should consider proper access to the inside of boxes for the inspection of post tensioning tendons. Consideration of life cycle costs should be made in order to assess alternatives. Extended service life of bridges is possible, but the potentially higher initial costs may need to be justified. The following lists expectations for concrete bridges being designed today:

- Best practices
- Improved durability
- Extended service life (75 to 100 years)
- Minimize deterioration
- Resiliency for extreme events

The following measures may be taken to achieve extended service life for concrete bridges:

- Proper detailing
- Strict QA/QC
- Increase concrete clear cover
- Better detailing of joints, with possible use of integral abutments
- Discourage the use of asphalt overlays (to prevent entrapped moisture)
- Provide overlays to protect the bridge deck system only with proper drainage
- Usage of high performance materials (High Performance Concrete [HPC], Self-Consolidating Concrete [SCC], Lightweight High Performance Concrete [LW/HPC], stainless steel, Fiber Reinforced Polymers/Plastics [FRP], coated steel, Fiber Reinforced Concrete [FRC])
- Adaptability of functionality (Design for inspectability and future replacement and/or rehabilitation)
- Consider future requirements for widening the bridge
- Scour monitoring systems
- Consider redundancy in bridges
- State oversight of bridges
- Better drainage system

Concrete bridge resiliency against extreme events may be enhanced through the following measures:

- Cross frames

- Continuous spans
- Single vs. multi load paths
- Failure modes and load paths
- Engineering judgment and flexibility in design and detailing
- Special scour inspection
- Assessing of post-fire residual properties
- Assess the ability to reopen the bridge soon after the event
- Ways to alert the public

When designing bridges for extreme events or rehabilitating a bridge for extreme events, situations could exist when two different extreme events would require opposing repair techniques. Identifying potential extreme events for a given location/bridge are critical to assessing risk and the probability of these events occurring should be evaluated. Better planning could be used to combine projects to the benefit of (1) reducing user costs (one construction project rather than two or more) and/or (2) using resources effectively by assessing future plan/needs. This type of work needs to be evaluated on a case-by-case basis.

Scour is a critical issue that needs to be adequately addressed during bridge design. Some studies have shown that scour is the number one cause of failure in bridges.

Rapid construction methods should be considered during the bridge design process where appropriate for both superstructure components as well as substructure components. As more projects utilize precast units there could be the potential for some shapes/components/etc. to become standardized. Standardized precast units will make rapid replacement in an emergency situation even more viable. A national model needs to be developed in order to better quantify user costs as part of the total cost of the project. Other items that need to be further developed to better implement rapid construction of concrete bridges include:

- Connection details for precast concrete
- Heavy equipment such as Self Propelled Modular Transporters (SPMT)

Materials

New materials that are currently being implemented in concrete bridge design/repair include:

- FRP rebar and sheets
- Lightweight concrete
- New non-shrink low-bleed high performance grouts
- New coatings such as Polyurea to increase deck life

- High Performance Concrete / Ultra High Performance Concrete (HPC/UHPC)
- Self-consolidating concrete (SCC)

These materials need to be fully understood so that they can be properly utilized. Design guidelines and code provisions are being developed for many of these new materials.

Condition Inspection

The qualifications required of bridge inspectors needs to be reviewed by the industry. For example, should separate qualifications be required for complex structures?

Another key item to obtaining high quality inspections is the need to retain inspection staff. Inspection work can be extremely repetitive and tedious; so there is a need to keep inspectors interested in their work. Having different inspection teams inspect a bridge during different cycles may be helpful for inspection diversity, so that the same team isn't always looking at the same bridges. This will also provide a cross check of the ratings provided by each team leading to greater consistency in visual inspection ratings. There is also a need to provide various career opportunities in the inspection field along with providing competitive salaries and benefits. The possibility of a peer exchange program for inspectors was discussed to the extent that it could provide a check of inspector ratings; it was mentioned in the main session that regional programs of this kind do exist but could possibly be expanded.

Advanced detection technology and techniques are needed to detect what is occurring inside the bridge structure. For concrete bridges, the inspection of the following critical elements presents areas of particular challenge:

- Post-tensioning tendons
- Advanced detection of rebar corrosion below the surface of decks

Specialized training and certification for inspectors using advanced technologies must be provided to ensure that these technologies are being applied and interpreted correctly.

Construction

Quality control is essential to providing durable structures. It is essential that the requirements of the Contract Documents be enforced during construction. Proper training of construction workers and inspectors so that they understand the plan and specifications requirements will help to achieve this goal. For example, if the worker understands why a 14 day wet cure is so important to the curing of HPC concrete, he will be more likely to make sure that the requirement is properly executed in the field.

Performance-based specifications should be used to help facilitate innovative technology. In addition, value engineering policies needs to be reevaluated to provide additional incentive for Contractors to come up with and implement innovative approaches and materials.

Technology for Monitoring Bridges

The discussions regarding sensor technologies for bridge monitoring focused on sensors to detect damage, assess performance, evaluate repair effectiveness, provide better data for design, provide early warning of failure, monitor load paths, and evaluate damage. It was mentioned that there are many types of monitoring and that not all structures warrant monitoring. The goal of the monitoring program should be identified in order to properly design the monitoring system and determine what data is expected.

Monitoring can be either short-term or long-term, assess local or global behavior/properties, and can be triggered by specific events. In terms of the sensors themselves, it was noted that they are often expensive, that the durability needs to be improved, and that periodic calibration would be beneficial for accuracy in long-term installations. In any structure, it is difficult to monitor for the unknown (e.g., instrumentation to alert of imminent failure) since only certain locations can be monitored and multiple failure mechanisms exist.

Sensor types discussed included fiber optic, strain gages, acoustic emission, accelerometers, moisture indicators, chloride indicators, ground penetrating radar (GPR), and GPS/video monitoring to name a few. Future needs include monitoring systems that minimize post-processing and use established triggers for data collection, inspector training on sensors, sensors capable of assessing unknown foundation details (GRP was mentioned but it was decided that it may not be sensitive enough) and wireless sensor communication reliability needs to be improved. Future trends will be for new construction to be instrumented rather than the monitoring systems being added to the structure at a later date.

Policy

Concrete bridge deterioration is a national "emergency". The importance of bridge maintenance needs to be prioritized in the minds of the public in order to obtain adequate resources. The critical policy steps that need to be addressed are:

- Vulnerabilities need be identified and prioritized so that resources can be directed to where the problems are.
- Design and inspection criteria should be reevaluated. It may be appropriate to vary the design/inspection criteria in accordance with a risk-based approach and required performance
- The current practice of allowing bridges to deteriorate in order for the owner to get federal money to replace them must be eliminated.

- Our current system is reactive rather than proactive. This could be changed if the potential for setting aside funds for specific bridges could be realized at the time they are built. These funds would be dedicated to that particular structure to be used throughout the structure's life.

8.4 Cable Supported Bridges

Cable-supported bridges have issues of concern related to strength vs ductility as the high-strength cable wires although allowing for longer spans, experience reduction in ductility. Cable durability is also a concern and various protection systems are being considered. Potential for excess displacements during seismic loading is an issue. Replacement of cable-supported bridge decks has different requirements than conventional slab-on-girder bridge deck replacements. Suspender rope design can impact durability and inspectability. Inspection and monitoring provide good return on investment.

Overview of the Breakout Discussion

The committee members discussed the following issues of concern to the Cable Supported Bridge Community:

- Quality control / Sample size required for strength testing of wire.
- Study of the potential for polymer coating over the wires to improve performance.
- Issues of adverse effect on ductility in the current pursuit of higher strength bridge wires.
- Seismic issues
- Deck durability in cable-stayed bridges.
- Cable Durability
- Suspender Ropes.
- Stay Cable Vibration.
- Inspection and Monitoring.

Better quality control and sample size is required for strength testing of wires. Currently 5 to 10% of coils are tested, but it is unclear what more is needed. There is a relationship between sample size and estimation of error.

In the manufacturing process rod coils are drawn into wires, and tests are currently conducted from samples taken from either ends. This sampling procedure, however may not be representative of the middle section, i.e., the section that is actually used on bridges. This is an area needing further investigation.

An overview of production testing for the manufacture of wire/strand/rope was discussed. In the presence of failed tests, the number of samples taken is increased.

Great advances in wire manufacturing and metallurgy as exemplified by the Akashi Kaikyo bridge have been seen in Japan. There have been some improvements in rope making technology, primarily in terms of reduction in cross-over points. Connections in wire ropes have also improved. Casting technology has produced items with the same quality as forgings. Improvements in lubrication during rope manufacture have also been seen. Improvements in metallurgy, leading to higher strength, may have an adverse effect on ductility. However, this needs to be proven and time is always the best laboratory.

Moving forward, there is a potential for the application of polymer coatings over wires to improve performance. However the benefits may have their downsides, such as retaining water under the polymer coatings.

Construction and design issues were discussed as well as material issues. One of those issues is the potential of minimizing hydrogen embrittlement by changing the composition of the high strength steel wires.

Live load configurations on long span bridges, seismic considerations, and aerodynamics were discussed. During a seismic event with large vertical excitation, behavior of long period structures in general, are of concern. Retrofit designs may cut across a number of issues.

Addressing deck durability, currently there is a large variation in requirements for deck replaceability. For a 100 year + bridge life, issues should be explicitly addressed by designing a deck for a 100 year life or allowing for easy (relative) replacement. We may be achieving a 100 year deck today, however there is not enough evidence to date to support this. Many options for building durable decks are available (FRP, stainless steel reinforcing bars, orthotropic decks, overlays, etc.)

On cable durability, up until now, there has not been a way to arrest or mitigate cable degradation. Dehumidification is a very promising technology, both in anchorages and along the cable length. Oiling of cables has been a standard treatment, but its benefit is questionable.

Over-looped versus under slung design of suspender ropes may have an impact on durability, and inspectability.

Stay cable vibrations is a major issue. However there is much ongoing research where the issue is being addressed including cable vibration during construction, and in service, and on ways to retrofit to mitigate this problem.

Acoustic technology was discussed as a good method for inspecting and monitoring of cables but it is important to have a baseline understanding of cable strength from which to subtract the lost capacity of wire breaks. It is important to establish such a baseline to identify new wire breaks, starting from a given point in time using the acoustic monitoring technology. Two main challenges remain to be overcome with the use of acoustic monitoring technology. Those are the verification of the presence of a true wire break (not noise), and the ability of pinpointing the exact location of the break along the cable length and in the cable cross-section.

8.5 Bridge Security

Bridge security is one hazard within a multi-hazard environment and must be prioritized with other hazards using risk-based assessments. Bridge security performance issues are related to serviceability, durability, and potential load capacity reduction caused by hardening. Performance issues may also cause special inspection requirements and thus affect bridge management. Sensor technology applications should address both security and structural health monitoring needs. Further discussion is needed related to the security requirements for the National Bridge Inventory. Basic guidelines are needed immediately to improve bridge performance for security. Performance-based security design that considers all four "D's" (Detect, Deter, Deny, Defend) should be developed as part of a consistent, multi-hazard risk management process.

Overview of the Breakout Discussion

The bridge security breakout team addressed the following questions:

- Seven years later, is bridge security still an issue?
- Can evolving bridge maintenance/monitoring technologies help mitigate terrorist threats?
- Can better bridge management help?
- Are there any potential performance issues caused by bridge security?

Breakout team members concluded that bridge security is still an issue, as one more hazard within a multi-hazard environment. Risk-based assessments must prioritize the hazards. A consistent, multi-hazard risk management process is critical and must be established.

Mitigation is a systematic approach, and all four "D's" (Detect, Deter, Deny, Defend) are integral. Mitigation is worthless without a rapid and capable response. Response and recovery is an important mitigation strategy and most applicable to the majority of bridges. Pre-designed bridges and pre-emplaced materials help facilitate rapid recovery.

Operational issues that focus on saving lives are important. Sensors should be tied to incident management (crowd/traffic control, damage detection, etc.), and state bridge engineers should be part of the incident command system for bridge events, e.g., collapses.

Structural health monitoring technology can be very beneficial to bridge security. This can work the other way around, that is, use security technology (like intelligent video) for additional purposes. We should nurture that natural symbiosis. Video cameras may not prevent an incident but are very useful for post-event investigation.

Significant debates are occurring about security requirements for the NBI. Access to the NBI can conceivably help terrorists prioritize targets, although little information is available within the NBI for actual attack planning.

There are many ways to improve bridge performance for security, including standoff, redundancy, and continuity. As previously mentioned, bridge security performance issues are related to serviceability, durability, and potential load capacity reduction caused by hardening. Performance issues may also cause special inspection requirements and thus affect bridge management. Basic guidelines are needed immediately to improve bridge performance for security, but detailed guidelines are a long-time coming. Performance-based design is inevitable and we should be moving toward it. This would be a good mandate for the SEI Bridge and Tunnel Security Committee. The key is to include bridge security as part of a consistent, multi-hazard risk management process.

9. CONCLUSION AND SUMMARY

The evolution of bridge technology has come about with improvements in science and hence structural theories, but by far, through improvements in construction material technology. The long span suspension bridges became possible only after the development of high strength wires. Today with the development of new advanced materials such as high performance concrete, high performance steel, fiber reinforced polymers, and advanced wood composites, new possibilities emerge. The majority of today's bridges were designed based on knowledge that is at least 50 years old. If things are to change, we need to move forward beyond incremental improvements, but this requires risk taking which has been difficult to do for infrastructure owners. Looking ahead we can see the possibilities of new bridge designs and systems being developed utilizing better materials; however, we also have a large investment in our existing inventory that needs to be maintained to safely carry growing traffic needs through proper inspection and maintenance. Although there is a law requiring routine bridge safety inspections every two years, the shortfall with current inspection methodology is that it is largely based on visual inspections that can be subjective. Although Non-Destructive Evaluation (NDE) technologies exist that can detect defects and provide quantitative information about the member being inspected, there are challenges that remain. These include being able to rapidly evaluate deterioration in all materials and member types, improving the reliability and quality of inspection methods, standardization of the technologies, and the costs.

A 20-year program monitoring performance of bridges is being initiated by the FHWA. It is hoped that the data generated on bridge performance over this long-term period will lead to enhancements in characterization of bridges, improvements in reliability of performance, better reliance on inspection data, and overall improved models predicting the condition of our bridges.

Participants to the workshop included members of the bridge engineering community with interest in improving our transportation infrastructure. They were given the charge to discuss (1) bridge design issues including best practices in design and detailing that could be used to improve durability, extend service life and prevent premature deterioration, (2) performance measures needed to better determine bridge condition, (3) technologies that could be used to monitor bridge life and assess condition, and (4) improving decision-making through comprehensive collection and evaluation of bridge performance and operations data and other topics which the groups felt were of importance.

Key Outcomes

There are many similarities in the behavior and hence performance of bridges even of different materials mostly due to similarities in design. However there are also many unique differences as a result of the differences in material used to construct these bridges. Attention to details during the design stage, construction and material quality control, drainage and moisture control, inspection frequency and inspectability were themes common to all groups. The innovations in and eventual greater use of sensors and sensing systems were perceived as positive developments for aid in inspection and condition monitoring to acquire better information on the health of bridges for all bridge types. Key outcomes are summarized below with respect to the charges given to the breakout groups.

Bridge Design

- The bridges that are designed today could last 75-100 plus years, if they are designed and constructed properly, with good quality control during material selection, fabrication and construction, and if periodic maintenance is conducted. Following best practices and with the use of new materials we can expect increased durability, extended service life, minimal deterioration, and resiliency for extreme events. However, designing for security is still at its infancy as much more research needs to be conducted.

- Some of the best practices discussed include paying attention to structural details, avoiding leaking deck joints, and providing for inspectability. Deck joints which lead to leaks can be a problem for all bridge types as it can lead to corrosion of steel in steel bridges, corrosion of reinforcing steel in concrete bridges, decay of wood in timber bridges, and corrosion of fasteners. Joint improvement would eliminate the root cause for a large percentage of corrosion and decay problems.

- The bridge design process must address performance needs and future repairs/inspections. Providing design details and performance specifications into initial designs and contract documents for more long-term durability and improved rehabilitation efforts is seen as a key for longer service life.

- In designing for security, performance-based security design that considers the four D's (Detect, Deter, Deny, Defend) should be developed as part of a consistent multi-hazard risk management process.

- A major factor which is leading to poor bridge performance and reduced service lives of timber structures was seen as being lack of sufficient education and knowledge by engineers about timber bridges (extending across the design-fabrication-construction-inspection-load ratings spectrum), because timber is the least familiar bridge material.

Performance Measures

- The processes which reduce the life of structures include improper quality assurance and quality control during fabrication, handling, storage and during construction for all material and bridge types. Many of the concrete bridge deteriorations that take place are caused by inadequate construction practices, concrete production and finishing techniques. The deterioration of timber bridges is accelerated by improper storage and handling during construction, in addition to poor detailing, inadequate drainage, improper protection of end grain areas, inadequate moisture management, and over-reliance on chemical preservative treatments. Most fatigue and fracture of steel bridges occur due to inadequate or improper detailing at the design stage and/or poor quality control at the fabrication stage. In addition to fatigue, corrosion is also a major issue with steel bridges, much of which can be alleviated with proper quality control including proper surface preparation, and proper application of paint and coating systems.

- The critical deficiency in the type of data that is currently collected in standard bridge inspection/ management practices includes the subjective nature of the inspection data. Too much reliance is given on visual inspection. It was a general feeling that the information that is currently gathered today is not adequate to judge the performance of bridges. Although visual inspection will never be replaced and does not need to be, it can be supplemented with quantitative inspection data (bridge monitoring), and better forecasting methodologies. Non-Destructive Evaluation (NDE) technologies can also supplement visual inspection.

- Concrete can deteriorate due to many causes, including cracking, scaling, delamination, spalling, chloride contamination, efflorescence, ettringite formation, honeycombs, pop-outs, wear, collision damage, abrasion, overload damage, and reinforcing steel corrosion. Direct performance measures discussed for concrete include load distribution, deflection, and strain/stress.

- Corrosion and fatigue are two major deterioration issues for steel bridges. Performance measures that lead to quantifying the remaining fatigue life, identifying the onset of problems in suspect details, and quantifying the rate of corrosion were discussed for steel bridges.

- Specific performance measures discussed for timber bridges included data on early decay detection, in-situ moisture content, and live load strain distribution.

- Issues for cable supported bridges include high strength steel wire vulnerabilities and inspectability. Performance measures discussed were detection of stages of corrosion, and effectiveness of cable protection systems.

- In terms of security, issues discussed to improve performance included providing standoff, redundancy and continuity.

Technologies to Monitor Bridge Life and Assess Condition

Technologies exist today for conducting nondestructive evaluation inspections, monitoring bridge life, and assessing bridge condition; however, not much of this is used in day-to-day operations. This may be due to a number of factors including cost, difficulty in data interpretation, life of sensors and sensing systems compared with the life of structures being investigated, rapid changes in technology, and inadequate understanding of what is needed for assessing different bridge types.

Advanced NDE technologies and techniques are needed to detect what is occurring inside the concrete bridge members, particularly to check on the condition of prestressing tendons in beams, and rebars in decks as bridges age. Inspecting cables on cable supported structures is still a challenge. There has been very little advancement in new NDE tools for inspecting timber structures. As corrosion and fatigue are major issues with steel bridges, being able to detect and quantify the deterioration is still a challenge.

The needs discussed include:

- Developing early warning systems to detect onset of corrosion, the start of internal damage, and moisture content;
- Further development of embeddable sensors or remote sensing devices that can more effectively characterize defects in members;
- More work in the area of embedded array of sensors that can trigger appropriate remedial action;
- Sensors to detect damage, assess performance, evaluate repair, provide data for design, provide early warning of failure, monitor load paths and evaluate damage;
- Sensors that are durable, low cost, low power, wireless, miniature, embeddable, and with high signal/noise ratio.
- Ability to measure deflection/strain under service loads;
- Development of economical NDE inspection tools and training at the local level;
- Data to determine when and how frequently overloads occur, as common occurrence of overloads has an impact on fatigue life of structures; and
- Inventory of fatigue crack locations, and assessment of problem details, repair and retrofit procedures and effectiveness of retrofits.

Improvements in Decision Making

- The physical separation between design, construction, inspection, maintenance and research that exists today needs to be changed so that one can learn from the other and make relevant improvements. A need for a circular design process that fosters more of a life-cycle approach in all aspects was discussed.

- Routine inspection, maintenance, and load rating were areas highlighted by the Timber Bridge Committee as areas needing improvement in decision making.

- The Concrete Bridge Committee discussed at length bridge inspection /inspector needs. A key item to obtaining high quality inspections is the need to retain inspection staff; have inspectors inspect different bridges, which ensures cross checking of ratings; having a peer exchange program for inspectors; and having a specialized training and certification program for inspectors using advanced technologies.

- The Steel Bridge Committee discussed having a comprehensive collection and evaluation of bridge performance and operations data that would reflect more accurately the decisions that are made for maintenance, repair and replacement, so that resources are spent wisely.

This was the first workshop developed by the bridge technical committees of the ASCE/SEI Bridge TAC and focused on bridge deterioration issues and ways to enhance bridge performance. The next steps include sharing information discussed these two days with the larger bridge community including AASHTO, FHWA, consulting engineers, educators, and others, and increasing awareness to continually improve the performance of bridges across the Nation. At a future date(s) the Bridge TAC plans to address other issues of importance to the bridge community.

Many of the presentations from the Workshop have been posted on SEI's website at http://content.seinstitute.org/committees/bridges.html.

APPENDIX A

ASCE/SEI Bridge Workshop:

Enhancing Bridge Performance

Co-sponsored by the Federal Highway Administration

February 21-22, 2008

ASCE Headquarters, Reston, Virginia

Bridge Workshop Agenda

Day 1		
8:00	Registration and Breakfast	
9:00	Welcome and Workshop Objectives	Sheila R. Duwadi, P.E., M. ASCE Team Leader, FHWA; Chair, ASCE/SEI Bridge TAC Jim Rossberg, P.E., M. ASCE Director, Structural Engineering Institute (SEI), ASCE Patrick J. Natale, P.E., F. ASCE Executive Director, ASCE Gary Henderson, M. ASCE Director, Office of Infrastructure R&D, FHWA
9:30	Evolution of Bridge Technology	Tom Ho, Ph.D., P.E. Vice President, T.Y. Lin International
10:00	Enhancing Bridge Performance - A Long Term Vision	Steven B. Chase, Ph.D., M. ASCE Former Chief Scientist, FHWA (retired)
10:30	Break	
11:00	Technologies for Condition Assessment of Bridges	Glenn Washer, Ph.D., P.E., M. ASCE Assistant Professor, University of Missouri
11:30	Overview of the FHWA's Long Term Bridge Performance Program	Hamid Ghasemi, Ph.D. Research Structural Engineer, FHWA
12:00	Lunch	

1:00 – 4:30	**Bridge Deterioration Issues and Performance Measures -** 25 minute presentation by each committee chair or designated representative on bridge deterioration issues.	
1:00	Steel Bridges	Reagan Herman, Ph.D., A.M. ASCE Senior Lecturer and Assistant Research Professor, Johns Hopkins University; Chair – Steel Bridge Committee
1:30	Timber Bridges	James Wacker, P.E., M. ASCE Research Engineer, U.S.D.A., Forest Service, Forest Products Laboratory; Chair – Timber Bridge Committee
2:00	Concrete Bridges	Nur Yazdani, Ph.D., P.E., F. ASCE Professor and Department Chair, Dept. of Civil Engineering, University of Texas at Arlington; Chair – Concrete Bridge Committee Danielle D. Kleinhans, Ph.D., P.E., M. ASCE Senior Engineer and Group Manager, CTLGroup
2:30	Break	
3:00	Bridge Management, Inspection and Rehabilitation	Sreenivas Alampalli, Ph.D., P.E., F. ASCE Director, Bridge Evaluation Services Bureau, New York State Department of Transportation; Chair – Bridge Management & Inspection Committee
3:30	Cable Supported Bridges	Khaled Mahmoud, Ph.D., P.E., M. ASCE President, Bridge Technology Consulting; Chair- Cable Supported Bridges Committee
4:00	Bridge Security	James Ray, P.E., M. ASCE Research Structural Engineer, U.S. Army Corps of Engineers, Engineer Research and Development Center; Chair, Bridge Security Committee
5:00 – 6:00	Meet and Greet Reception	

Day 2		
8:00	Breakfast	
9:00	Recap of Day 1 presentations and charge to breakout groups: • Steel Bridges • Timber Bridges • Concrete Bridges • Cable Supported Bridges • Bridge Security	Sue Lane, P.E., M. ASCE Manager, Codes and Standards, ASCE Sheila R. Duwadi, P.E., M. ASCE
9:20	Improving Bridge Performance – Breakout Group Discussions on: • Bridge deterioration issues and critical deficiencies in the type of data currently collected in standard bridge inspection/management practices; • Technologies that could be used to monitor bridge life and assess condition; • Improving decision-making through comprehensive collection and evaluation of bridge performance and operations data.	All Attendees
12:00	Lunch	
1:00	Report-out – Breakout Groups: • Steel Bridges (20 min) • Timber Bridges (20 min) • Concrete Bridges (20 min) • Cable Supported Bridges (20 min) • Bridge Security (20 min)	Sheila R. Duwadi, P.E., M. ASCE Reagan Herman, Ph.D., A.M. ASCE James Wacker, P.E., M. ASCE Nur Yazdani, Ph.D., P.E., F. ASCE Danielle D. Kleinhans, Ph.D., P.E., M. ASCE Khaled Mahmoud, Ph.D., P.E., M. ASCE James Ray, P.E., M. ASCE
2:45 – 3:30	Conclusions and Next Steps	Sheila R. Duwadi, P.E., M. ASCE

APPENDIX B

Presenter Bios

Sreenivas Alampalli, Ph. D., P.E., F. ASCE, is the Director of the Bridge Evaluation Services Bureau at the New York State Department of Transportation. His Bureau provides data collection and evaluation services to facilitate the preservation, structural integrity, and safety of existing bridge infrastructure in New York State. His responsibilities include managing Bridge Inspection, Inventory, and Safety Assurance programs. Dr. Alampalli also has extensive experience in structural engineering related research. Dr. Alampalli obtained his Ph.D. and MBA from Rensselaer Polytechnic Institute, M.S. from IIT, Kharagpur, India, and B.S. from S.V. University, Tirupati, India. His interests include infrastructure management, innovative materials for infrastructure applications, nondestructive testing, structural health monitoring, and long-term bridge performance. He authored or co-authored more than 200 technical publications. Dr. Alampalli is a Fellow of ASCE and ASNT, and is a member of several technical committees in TRB, ASCE, and ASNT. He also serves as an Associate Editor of the ASCE Journal of Bridge Engineering.

Steven B. Chase, Ph. D., M. ASCE, recently retired as the first Chief Scientist with the Federal Highway Administration (FHWA) Turner Fairbank Highway Research Center after a career spanning 30 years, the final 15 years in research. He has been a research project manager and Technical Director for Bridges and Program Manager for Infrastructure R&D. In his career with FHWA, Dr. Chase served as a bridge engineer in all elements of the FHWA organization. His research interests focus on the broad area of bridge management systems, with particular emphasis on the application of information technology to the management of highway bridges at the national level. Dr. Chase is also very active in the development and application of innovative nondestructive evaluation technologies for highway bridges. He received his doctoral degree in Civil and Environmental Engineering from the University of Rhode Island in 1991. He is a member of the American Society of Civil Engineers, the Transportation Research Board, and the American Geophysical Union. Dr. Chase is the author or editor of more than 60 technical publications and invited presentations.

Sheila Rimal Duwadi, P.E., M. ASCE, is the Team Leader for the Bridge Safety, Reliability and Security team of the Federal Highway Administration at the Turner Fairbank Highway Research Center. The Team is responsible for research and development of bridge technologies and methodologies for design and construction for all extreme events including terrorism. In addition to being a Team Leader, Ms. Duwadi is also the Program Manager for Bridge Security R&D, and for Timber Bridge Research. She is active within the Agency in security related activities and represents the

Department of Transportation on the White House Office of Science and Technology Policy's Subcommittee on Disaster Reduction. Ms. Duwadi is active in a number of the ASCE/SEI technical committees. She is the chair of the Bridge Technical Administrative Committee, member of the Technical Committee on Bridge Security, member of the Design Loads on Structures during Construction Committee, and past chair of the Technical Committee on Timber Bridges. In addition she is the FHWA Liaison on a number the Transportation Research Board projects and on the American Association of State Highway Transportation Officials bridge subcommittees. Working for the FHWA since 1984, Ms. Duwadi has had numerous responsibilities including bridge design, and research in the areas of steel, concrete, and timber bridges and non-destructive evaluation technologies. She is a graduate of Washington State University where she received her Bachelors Degree in Civil Engineering and from Oregon State University where she received her Masters Degree in Civil Engineering.

Hamid Ghasemi, Ph. D., is a Research Structural Engineer with FHWA. He joined the staff in the Office of Infrastructure at the Federal Highway Administration's Turner-Fairbank Highway Research Center in 1994. He has been involved with numerous research studies and projects addressing the needs of the bridge community with emphasis on structural health monitoring, structural dynamics, seismic related issues, computer modeling, and structural analysis. Dr. Ghasemi has authored 13 HITEC technical reports on the performance of seismic isolation bearings subjected to dynamic loads. He served on the AASHTO T-3 Subcommittee that developed the 1999 AASHTO Guide Specifications for Seismic Isolation Design. He was a member of the damage assessment teams that evaluated highway conditions after the 1994 Northridge, California and the 1999 Kocaeli and Duzce, Turkey earthquakes. Dr. Ghasemi was recently appointed the program manager for the FHWA's Long-Term Bridge Performance Program. This is a major new initiative with the objective of improving knowledge of bridge performance. In 2001, Dr. Ghasemi was named FHWA Engineer-of-Year, an annual award recognizing engineers in the Federal Highway Administration.

Gary L. Henderson, M. ASCE, is the Director of the Office of Infrastructure R&D at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center in McLean, Virginia. In this position he is responsible for technical direction and administration of FHWA's program of research, development and technology on engineering aspects of pavements, bridges and other highway structures. In addition, he advises the Associate Administrator for Research, Development, and Technology and higher management within the FHWA on aspects of research, development and technology relating to engineering and highway operations. Mr. Henderson, a member of the Senior Executive Service, has been in this current position since 2005. Prior to this he was the Division Administrator in FHWA's District of Columbia Division where he was responsible for administrating the Federal-aid highway program in the District. He has been with the FHWA since 1970 entering the FHWA as a Highway Engineer Trainee, and has since held numerous technical and managerial positions. Mr. Henderson is a graduate of the Tennessee State University with a BS in civil engineering. He also holds a Master of Engineering Administration degree from the George Washington University, and is a graduate of the American Association of State Highway and Transportation Officials Highway and Transportation Management Institute, and the Federal Executive Institute.

Reagan Sentelle Herman, Ph. D., A.M. ASCE, is a Senior Lecturer and Assistant Research Professor in the Department of Civil Engineering at Johns Hopkins University. Her research interests focus on the design and behavior of steel bridges and her recent projects have included studies of innovative bracing approaches for steel plate girder bridges, impacts of thermal effects on steel plate and box girder bridges, and effects of web and flange imperfections on the behavior of steel girder bridges. She is Chair of the ASCE/SEI Steel Bridges Committee and is a member of the Transportation Research Board Steel Bridges (AFF20) and Fabrication and Inspection of Metal Structures (AFH70) Committees and the Structural Stability Research Council Committees on Plate and Box Girders and Horizontally Curved Girders. Her awards include the Robert J. Dexter Memorial Lecture from the AISI Steel Bridge Committee and the AASHTO Technical Committee for Structural Steel Design Awards (2006), the Vinnakota Paper Award from the Structural Stability Research Council (SSRC) for the paper entitled "Strength of Metal Deck Forms Used for Stability Bracing of Steel Bridge Girder" (2005), and the Top Research Innovation Award from the Texas Department of Transportation for the project entitled "Lateral Bracing of Bridge Girders using Permanent Metal Deck Forms" (2004-05). Prior to joining Johns Hopkins, Dr. Herman was on the faculty at the University of Houston where she had a close working relationship with the Texas Department of Transportation. Dr. Herman received her M.S. and Ph.D. degrees in Structural Engineering from the University of Texas at Austin, and her B.S. degree in Civil Engineering from North Carolina State University.

Tom Ho, Ph. D., P.E., is a Vice President of T.Y. Lin International, where his primary responsibilities include project management, supervising the preparation of design calculations and drawings, and full construction services for bridges, transit, and special structures. He has over 20 years of experience managing award-winning structural design projects, and over 15 years of experience leading seismic retrofit projects for both buildings and bridges. Over the last few years, Dr. Ho has been involved in the design of several high-profile bridge projects in high-seismic areas of China. He reviewed all plans for the Shibanpo Bridge in Chongqing, a seven-span box girder crossing of the Yangtze River, which is now the longest box girder bridge span in the world. He served as Project Director for the design of the $190 million steel tied-arch Caiyuanba Bridge, also a major Yangtze River crossing, which will become one of the longest tied-arch bridges in the world upon completion. For the new San Francisco-Oakland Bay Bridge East Span, which includes the world's longest self-anchored suspension bridge, Dr. Ho served as Production Manager and oversaw the production of over 1,000 sheets of plans for the project. He is currently working on the Bay Bridge construction site providing construction stage services. Dr. Ho is coordinating author of "Seismic Retrofitting Guidelines for Complex Steel Truss Highway Bridges" for FHWA, published in 2006, and is the author of three papers on Finite Element Evaluation Procedures. He is a member of the Chinese Institute of Engineers. Dr. Ho received his master's degree in Civil Engineering from Memphis State University in 1978 and his doctoral degree in Civil Engineering from the University of Colorado in 1984. He is a registered Professional Engineer in California and Utah.

Danielle Kleinhans, Ph. D., P.E., M. ASCE, works for CTLGroup in Skokie, IL where she is Group Manager for Structural Engineering and Mechanics. She currently serves as the secretary for ASCE/ACI committee 343 on concrete bridge design. Dr. Kleinhans has eight years of structural engineering experience, focused on the design and construction of bridges and on the use of fiber-reinforced materials for structural applications. Current projects include forensic investigations and litigation support for projects involving bridges, parking garages, and residential structures. Before joining CTLGroup, Dr. Kleinhans served as a structural design engineer with Modjeski and Masters, Inc., in Harrisburg, PA. She obtained her Ph.D. from the University of Missouri-Rolla and is a licensed professional engineer in three states.

Susan N. Lane, P.E., M. ASCE, is the Manager of the Codes and Standards Department of the American Society of Civil Engineers (ASCE). Ms. Lane manages the overall codes and standards program within ASCE which produces standards in all areas of civil engineering. She received her Bachelor's and Master's degrees from The Pennsylvania State University and is a licensed professional engineer in Virginia. Ms. Lane worked for the U. S. Department of Transportation's Federal Highway Administration (FHWA) for 13 years as a Research Structural Engineer and Team Leader, specializing in concrete bridges and high performance materials for bridges. Prior to joining FHWA, she designed and analyzed bridges and bridge components for Parsons Brinckerhoff in New Jersey and Virginia. Ms. Lane also taught a reinforced concrete design course at Catholic University in Washington, DC for six years, and worked for Fannie Mae as a financial engineer.

Khaled Mahmoud, Ph. D., P.E., M. ASCE, is the President of Bridge Technology Consulting and has over 20 years of diversified hands-on experience in the design, research, management, analysis, and rehabilitation of major bridge projects throughout the United States and abroad. Dr. Mahmoud is a bridge engineer who specializes in the design, strength evaluation and fracture behavior of bridge cables. An internationally renowned cable expert, he has been invited as visiting professor and keynote speaker in France, Italy, the Netherlands, Turkey, and the United Kingdom. He is the editor-in-chief of the Journal of Bridge Structures and the editor of three books on Bridge Engineering. Dr. Mahmoud is the Chairman of the Bridge Engineering Association, organizer of the New York City Bridge Conference. He is the chairman of the American Society of Civil Engineers' Committee on Cable-Supported Bridges. Dr. Mahmoud teaches Bridge Engineering & Fracture Mechanics at Polytechnic University in the City of New York.

Patrick J. Natale, P.E., F. ASCE, began his tenure as the Executive Director of the American Society of Civil Engineers (ASCE) in November 2002. Mr. Natale is responsible for the day-to-day management of the Society. He provides executive leadership to a staff of more than 230 and an active volunteer workforce of over 7,500, facilitating ASCE's tradition of supplying high-quality and high-value products and services to its members and other customers worldwide. In January of 1999, Natale was appointed the Executive Director of the National Society of Professional Engineers (NSPE). Prior to joining NSPE, he held numerous top-level management positions with the Public Service Electric and Gas Company (PSE&G) of New Jersey. During his 28-year career with PSE&G, he was responsible for managing sales, marketing, strategic planning and customer service. His most recent assignment was to lead the corporate effort to develop the process and systems required for deregulating the energy marketplace in New Jersey. In his community, Natale has served as Chairman of the Board for Goodwill Industries of New Jersey and as a member of the Board of Directors of the Chamber of Commerce and the American Red Cross. He has also served as an Assistant District Commissioner for the Boy Scouts of America. Natale holds a B.S. in Civil Engineering from Newark College of Engineering, and an M.S. in Engineering Management from the New Jersey Institute of Technology. He has completed the Executive Management Program at Yale University, and is a licensed Professional Engineer in New Jersey. He is also a Certified Association Executive (CAE).

Mary Lou Ralls, P.E., M. ASCE, is an engineering consultant and principal of Ralls Newman, LLC. She earned BSCE and MSE degrees from The University of Texas at Austin in 1981 and 1984, respectively, before joining the Texas Department of Transportation. At TxDOT she worked in various engineering positions before being appointed the state bridge engineer and director of the Bridge Division in 1999. Ralls retired from TxDOT in September 2004 after 20 years of service. She is a registered professional engineer in Texas and continues work to advance innovative bridge technologies. Ms. Ralls served as the ASCE/SEI Workshop report facilitator.

James C. Ray, P.E., M. ASCE, is a Research Structural Engineer with the U.S. Army Engineer Research and Development Center (ERDC), in Vicksburg, MS. He has been with the ERDC for over 22 years and has worked almost exclusively in the area of bridges. Since 9/11 Mr. Ray has been working very closely with the Federal Highway Administration on developing coursework to educate the bridge engineering community in the area of blast and blast effects on structures; in assessing bridges for vulnerability against terrorist threats; and has been involved in research to develop retrofit methodologies for blast protection. Mr. Ray is a Professional Engineer and received both his undergraduate and graduate degrees from Mississippi State University. He is the current chair of the ASCE/SEI technical committee on Bridge Security.

James A. Rossberg, P.E., M. ASCE, is the Director of the Structural Engineering Institute (SEI) of the American Society of Civil Engineers. SEI is a 21,000 member organization with over 120 committees working in four primary areas: technical activities; business and professional practice issues; promulgation of standards; and support of local structural engineering groups. Mr. Rossberg is also responsible for the overall codes and standards program within ASCE which produces standards in all areas of civil engineering. He received his Bachelor's and Master's degrees from Old Dominion University in Norfolk, Virginia and is a licensed professional engineer in Maryland where he practiced for 5 years prior to entering the world of association management. Mr. Rossberg has been with ASCE for over 15 years and, in addition to his other duties, serves as the secretary to the ASCE 7 standards committee on Minimum Design Loads for Buildings and Other Structures.

James Wacker, P.E., M. ASCE, has been an engineer with the Forest Products Laboratory in Madison, Wisconsin for the past 18 years. His past research has involved a variety of timber transportation structures. He played a key role in conducting a nationwide monitoring program that evaluated several stress-laminated, timber highway bridges in partnership with FHWA. His current focus is on various condition assessment, rehabilitation, and long-term monitoring techniques for timber bridges and other historical structures. Mr. Wacker is a graduate of the University of Wisconsin's Civil and Environmental Engineering Department. He currently serves as chair of the ASCE technical committee for timber bridges and is a registered professional engineer in Wisconsin.

Glenn Washer, Ph. D., P.E., M. ASCE, is an Assistant Professor at the University of Missouri – Columbia (MU). Before joining the University, Dr. Washer was with the Federal Highway Administration (FHWA) at the Turner Fairbank Highway Research Center (TFHRC) where he served as the director of the FHWA Nondestructive Evaluation (NDE) program. Dr. Washer has expertise in a wide variety of NDE technologies for the condition assessment of highway bridges, including ultrasonics, thermography, ground penetrating radar, radiography and the visual inspection of bridges. He has published more than sixty conference and journal papers on the development of NDE technologies and their application bridge condition assessment. Dr. Washer is an active leader in the technical community, chairing several committees related to the condition assessment of highway bridges. Dr. Washer is the chairman of the Transportation Research Board's (TRB) Subcommittee on the Nondestructive Testing of Structures and past chair of the ASCE committee on Bridge Management, Inspection and

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Nur Yazdani, Ph. D., P.E., F. ASCE, is the Chairman of the Civil Engineering Department at University of Texas at Arlington. His research includes concrete/timber bridge design, repair and hazard mitigation of civil infrastructure, FDOT concrete bridge technology, stress-laminated and SCL bridges, and utilization of steel fibers in post-tensioned bridges. During his career, Dr. Yazdani has received numerous awards for his teaching and research abilities and has secured more than $8 million from externally-funded research projects. Under his conception and leadership, the Center for Infrastructure Hazards has been established at UT Arlington. Dr. Yazdani serves on the editorial board of the ASCE Journal of Bridge Engineering and on NCHRP panels. He received the state of Florida 2005 Davis Productivity Award. Dr. Yazdani is a Fellow of ASCE and a registered professional engineer. He is a past president of the ASCE Tallahassee Branch, and the current Chair of ACI-SEI Joint Committee on Concrete Bridge Design. A leader in engineering education, he is an ABET Program Evaluator, and has chaired several committees dealing with graduate, curriculum and fundraising activities. Dr. Yazdani is also an active consultant to several government and private entities on infrastructure hazard related issues.

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Imbsen, Roy	Imbsen Consulting
Kaufman, Steven	Parsons Brinckerhoff
Matejowsky, Alan	HDR Inc.
Mo, Yi-Lung (Y.L.)	University of Houston
Moss, Gary	Federal Highway Administration
Womack, Kevin	Utah State University

* moderator; ** note-taker

D.4 Concrete Bridges – Breakout 2

Name	Affiliation
Kleinhans, Danielle *	CTLGroup
Brown, Michael	Virginia Transportation Research Council
Davidge, William	Wiley & Wilson
Elnahal, Shoukry	Federal Highway Administration
Hedayati, Ali	Parsons Brinckerhoff
Issa, Mohsen **	University of Illinois-Chicago
Janoyan, Kerop	Clarkson University
Roberts-Wollmann, Carin	Virginia Tech
Suksawang, Nakin	Florida International University
Tadros, Gamil	Speco Eng. Ltd, Canada
Virmani, Paul	Federal Highway Administration

* moderator; ** note-taker

D.5 Cable Supported Bridges

Name	Affiliation
Mahmoud, Khaled (Chair) *, **	Bridge Technology Consulting
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Kumarasena, Thusitha (Sena)	HNTB
Murphy, Thomas	Modjeski and Masters
Secules, Thomas	Wirerope Works, Inc.
Tang, Fang-Fu	The LPA Group, Inc.

Name	Affiliation
Yen, Phil	Federal Highway Administration

* moderator; ** note-taker

D.6 Bridge Security

Name	Affiliation
Ray, James (Chair) *	U.S. Army Corps of Engineers
Agrawal, Anil	City College Of New York
Alampalli, Sreenivas	New York State DOT
Capers, Jr., Harry	Arora and Associates, P.C.
Collins, Thomas	Collins Eng Inc
Durrant, John	ASCE
Englot, Joseph	HNTB Corporation
Ernst, Steven **	Federal Highway Administration
Ettouney, Mohammed	Weidlinger Assocs
Frangopol, Dan	Lehigh Univ
Rehm, Kelley	AASHTO
Western, Jeffrey	Wisconsin Department of Transportation

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APPENDIX E

Breakout Session Team Discussion Notes

E.1 Steel Bridges

The flip chart notes collected in the Steel Bridges breakout session were organized and filtered to lessen redundancy. The following pages present the reduced set of notes. The information discussed in the breakout session was arranged in seven topical areas: fatigue and fracture, corrosion, joints, inspection and maintenance, lead based paint, sensors and field assessment, and wrapping up.

Two key issues that specifically impact performance of steel bridges are corrosion and fatigue.

Fatigue and Fracture

- Now 60 to 70% of freight between states is on trucks. Said that 30 to 40% overloads don't get stopped. So we are not properly assessing fatigue life. With overloads we have more concern on distortion-, not stress-, induced fatigue. Can't accurately predict the results of this distortion induced fatigue well (thus in new design we used details to limit distortion).
- Need to define state of practice in addressing distortion induced cracks. Refine practice with respect to prediction of useful life.
- Collect data on fatigue cracks that have been identified. Where were they? What was the retrofit? Any problems with retrofit? More synthesis of this data - close loop in terms of evaluation of existing retrofit options to national recommendations on repairs.
- New bridges should be designed for infinite fatigue life. Is this economical? Yes for known types.
- Good opportunity for sensors.
- Need new sensor technology to detect actual stress not just change in stress. Need to know total stress state in the element.
- In absence of gage to measure actual stress need more information on residual stresses for different fabrication technologies and different materials.
- Need Long term monitoring of major crossings.
- For new bridges with HPS
    - Data on crack arrest. Toughness behavior in field.
    - Deflection stability especially for 100 ksi.
    - Optimize fabrication inspections to achieve reliability of fracture critical members.

Corrosion

- Need national collection/dissemination of corrosion prone details.
- Classic problem areas, like joint leaks, lead to significant percentage of corrosion problems. One way to address this is through use of jointless bridges. Recognize joints WILL leak so go jointless.
- Need better details to address debris accumulation and water drainage. Details that are not "pigeon friendly" to reduce/eliminate droppings accumulating on bridges. Use boxes for more structures without protruding areas where birds can roost.
- Main emphasis should be on better details, but better materials, like super smooth steel where water will run off the surface or concept like water "repellant" steel, could also generate benefits. Investigate new shapes and self-cleaning details.
- Maintenance is a key concern – clean debris accumulation before problem starts and then accelerates.
- Coatings and weathering steel are important. Coatings cannot solve problems with current inventory, but take results from coating studies and institute in new designs.
- Must have ongoing measurement of coating performance for new products. (Metallic coatings? Information from Naval NRC, Lawrence Livermore Lab. Nickel-Cr-Mb but not zinc - stainless steel like).
- Joints have key relationship with corrosion. Take extra effort to protect under the joints.

Joints

- Common situation that whole bridge looks good EXCEPT at (and beneath) the joints.
- Must share best practices for joints. Where do you go for information? What proprietary joints might be worth the cost? Need more joint specific data. Also mine data we already have on joints and the typical deficiencies that will result under the joints and must be repaired.
- Joints MUST be included in maintenance programs.
- Water management / drainage system is critical.
- Focus on cause and effect. Joint is source of problem – degradation of area under the joint is the effect. Then you have section loss and so now you have a safety problem.
- Design for replacement and maintenance; provide proper support of joint – some details shearing off. Proper installation is critical for desired joint performance
- Provide extra protection of metal beneath joints. Field galvanizing? Best metal coatings beneath joints. Very heavy paint at joint areas. Keep watching this area!
- Need maintenance when bridge opens - include this in construction contract.

- Florida DOT study (MOUSSA) – new joints installed by manufacturer and most failed within one year, some in months. Installation procedures not properly followed even by the manufacturer. Global notion of quality assurance across bridge: are elements performing as promised?
- Require warranties to keep contractor and/or joint manufacturer involved. Apparently this has been done by Florida DOT. (A problem is that many joint manufacturers only in business 5 or 10 years.) Results of scanning tours for countries that require warranty of bridges/bridge elements? One group member mentioned Missouri talking about 10 year bridge warranties.
- Have notion of pre-qualification - but in reality follow low-bid approach so not enforcing pre-qualification.
- For retrofit, rebuild joint and also repair deck and structure on several feet either side of joint top to bottom. NY did a targeted retrofit like this and significantly improved rating of repaired bridges.
- In general, the group did not view joints as a material problem. Good materials exist but must design, specify, install and maintain. With installation need strong inspection, then throughout life need strong maintenance program.
- Joints should be recognized as critical, even though not necessarily a safety concern, because of their profound effect on durability.
- Joint systems we currently use are difficult to reinstall and repair. Most states won't replace joints because of this difficulty.
- Need better joint design recognizing the joints won't last as long as the deck and will need to be repaired/replaced more frequently. Must be prepared for joint failure.
- Joint rating should probably be included in NBIS.

Inspection and Maintenance

- Need safety inspector out there, not just construction inspector. Make decision right there on site if safe or not. Not "4 or 5", the +/- 2 range doesn't cut it.
- Follow risk based inspection procedure– put money where it will ensure most important impact.
- Say you have a bridge that has a rating of 4 on the deck. Now bridge is said to be deficient, but not typically same criticality as low rating on super- or substructure.
- Need data differentiated by safety and serviceability.
- On inspections, need inspector to make judgment of effect of condition on durability.
- In sufficiency rating should take in importance of traffic on the bridge.
- Must not allow sufficiency rating to be biased to obtain funding.
- Put inspection weight on safety, not durability.

- Do element level inspection. Focus on critical elements like ends of girders at join, pins and hangers, eyebar, …
- Other countries not just assessing damage but identifying effect of damage.
- If not quantifying section loss we are not doing our job.
- First thing on inspection should be joints. If joint is in poor condition must be repaired or replaced.
- Target bridges with joint problems. Do repairs at joints and areas under the joints and should reduce deficiency percentage significantly (30, 40, more? percent). Have to be able to prove that with this much expenditure we obtain "X" amount of benefit. Need to show we can spend little and get a big benefit but don't have this kind of data.
- Do targeted retrofits to increase life of bridge. Have rating of 3 or 4 – bring it up to 5 or 6 and keep it there as long as you can.
- Need quantified performance measures for element ranked by criticality to be used in inspection. This is not in current National Bridge Inventory data.
- Need better appreciation from funding agencies that maintenance is important.
- Need program that links preservation money with maintenance money.
- We know there are simple things that will enhance performance – how do we get the money to get them done? Institutionalize policy we create on this.
- Recommend low maintenance bearings and collect data on bearings. Inspection must document current state of bearing (photos) – compare in subsequent inspections.
- Let's look at toll facility: Inspect bridge – obtain poor rating – next day maintenance is out on bridge to address the concern. Need this kind of non-deferred maintenance on public bridges. If we defer maintenance there is a higher cost later on. Tie funding to maintenance and prevention.
- Must have action following inspection, need clear path with money to make this happen. Must be institutionalized policy.
- Deferred maintenance is norm now. Must get data to show that repair of joints would have dramatic improvement on deficiency ratings with preservation program focused on joints. Some states have example programs of this kind. Requires element level inspection.

Lead Based Paint

- Cannot lump this topic with others due to specific environmental concerns.
- Deteriorating bridges can involve lead paint.
- Political drive/direction in addition to environmental.
- For issue of lead based paint – lead abatement drives whole decision process.

Sensors and Field Assessment

- In many cases existing sensors are adequate, but rational consistent design of inspection and preservation programs using existing sensors is lacking needed funding. Need funding for wider implementation of existing technology.
- Critical sensor deficiency is lack of corrosion sensor.
- Significant sensor deficiency is lack of sensor that can measure absolute, or total, stress rather than change in stress.
- NEED high precision surveying for measurement of deflection to speedup load testing. We are using stronger materials and lighter sections so they deflect more. Monitoring deflection is critical.
- If we have self contained load vehicle with sensors for near-traffic-speed load testing – run standard truck at, say, 40 mph – immediately pick up deflection data.
- Need more load testing data, especially for low life rated bridges. Must have this data to get better decision making on posting and allocation of bridge replacement funds. But this is expensive.
- Do proof test as part of construction acceptance
- Optical fiber strain gages worthy of more study.
- Monitoring system must be based on understanding of structural behavior to properly locate critical areas where sensors should be placed.
- Best approach to monitoring is risk based: instrument critical bridges. Periodic monitoring of critical areas on key bridges.
- Need some attention to longer period monitoring, structural response to thermal loads in bridges.
- Focus data gathering on key elements, critical elements for safety and service. Should identify critical elements at design stage. Critical areas can be flagged in Pontis and data collected on each inspection cycle. This data then needs to get back to national scale to continue creation of critical location database.
- One point that crosses all bridge types: do risk-based inspection instead of time-based inspection. Must have element level inspection.

Wrapping Up

- We do good job of writing elegant specifications but not enforced in the field.
- Need better education. Life-long learning in all phases of our business is critical.
- Must deliver key information to the person that needs to know it at the time they need to know it.
- Include impact of all decisions on life cycle costs
- Need to redefine performance measures to directly reflect safety and serviceability. Fracture critical is important issue here.
- For redundancy need redefinition for rational approach reflecting actual risk. Need more data to effectively address this goal.

E.2 Timber Bridges

- Bridge design – limited education and knowledge by engineers
  - Only few universities in U.S. offer timber-material or timber-structure courses
  - On-the-job training for timber bridges becoming less common
  - Results
    - Design/Construction of timber bridges is unfamiliar territory for engineers
    - Many recently constructed don't employ proper structural and durability detailing
  - Suggestions
    - Generate Best Practices Manuals
    - Conduct focused and comprehensive training
    - Get timber structures in more college curriculums
- Performance measures; may require research and development
  - Early decay detection
  - In-situ moisture content
  - Live Load strain distribution
  - Suggestions
    - Chemical test kits for early decay detection
    - Further development for moisture sensors
    - Fiber-optic embedded sensors being evaluated
- Technologies to monitor or assess condition
  - New techniques needed
  - Existing and other non-traditional NDE technologies
  - Suggestions
    - Inspector training
    - Economical NDE inspection tools
    - Ground penetrating radar
    - X-ray tomography
- Improve decision making
  - Routine inspection
    - Need to easily see signs of deterioration
      - Develop field manual or handheld software
    - Deterioration/serviceability issues vary with superstructure type
      - Develop guidance manual
  - Maintenance
    - Need improved rationales for more cost-effective approach

            - Develop manual with desired intervals
    - Load rating
        - Process should allow for improved condition ratings
        - Provide guidance for 'Timber Structural Load Rating Process'
    - Bridge closures
        - Inspectors need to recognize safety risks for closure
        - Develop guidance manual with examples and photos
- Other issues
    - Substructures also important for overall performance
        - Future workshops emphasize substructure deterioration and performance
    - Research needed on maintenance, inspection, and repair methodologies for extending service life of existing bridges
    - Serviceability issues also important, e.g., problematic asphalt wearing surfaces on cracking with panelized glulam deck systems

E.3 Concrete Bridges

Due to the number of Workshop participants who had experience and interest in concrete bridges, there were two breakout groups for concrete bridges. Therefore the results for each of the two concrete bridge breakout groups are presented in the following pages.

E.3.1 Concrete Bridges Breakout Group 1

- Performance?
    - Strength
    - Durability
    - Serviceability
    - Quantification
    - Ductility
- Visual Inspections
- Inspection Methods
    - Qualifications
        - Complex bridges
        - Specialized training
        - Retention (salary, perks)
    - Right tools
    - More comprehensive inspections. (political, cultural)
    - Design for inspectability
        - Post-tensioned corrosion
- Repair feasibility in the design process

- Scour
- Track vulnerabilities
- Look at successful techniques
- Interaction between groups
- Maintenance:
    - What worked or not worked (communicate)
        - Develop national database
    - Neglected maintenance
        - Lack of state funds
- Consultant to State communication
- ASCE provide bridge performance resources
- Construction Issues
    - Quality control
    - Specifications
    - Enforcement
    - Training of inspectors and contractors of why we do things
    - Communication between contractor/designer
    - Value Engineering improvements
    - Performance-Based Specifications
- Materials
    - Quality of concrete
    - HPC
    - Reinforcements
    - Coatings/Polyurea
    - Properties
    - Utilizing advanced material properties in design
    - Upper limits on strength
    - Research
        - coordination between committees
        - sharing of research to reduce redundancy
- Joints Leakage
    - Deck
    - Cold
    - Construction
- Quantifying Damage
    - Analysis Methods
- Rapid Replacement / Construction
    - Precast Concrete
    - Details
    - Fabrication Tolerances

  - Barges / Heavy Lifting Equipment
  - Incentives
  - Quantifying "User Cost"
  - National Model Needed
  - Evaluating All Costs
    - Detours, etc.
  - SPMT (Self-Propelled Modular Transporters)
    - FHWA website
- Consistent Extreme Event Approach
  - Various years
    - 1/10,000 vessel collision
    - Seismic 1,000 yr
    - 500 yr
  - How do we make the design criteria consistent
  - New Coastal Hazard Document coming out
- Deck: High Cost of Replacement
- Substructure
- Superstructure
- Foundation

E.3.2 Concrete Bridges Breakout Group 2

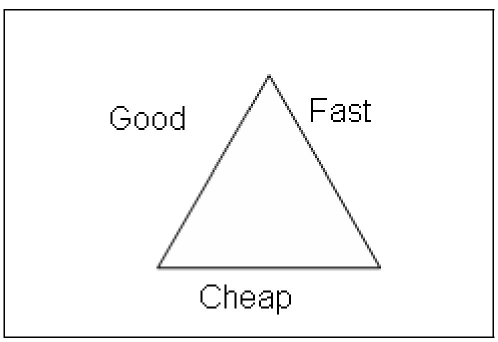
- Bridge Design
  - Expectations
  - Best Practices
    - Improve Durability
    - Extend Life
    - Prevent Deterioration
  - Resiliency for Extreme Events
  - Design
    - Deck 30-40 years
    - Substructure 70 years
    - Overlay
    - 100 Years Overall
    - $$ Cost-Benefit
    - Adaptability of Functionality
    - "Signature" vs. "Standard"
  - Details
    - Increased Cover
    - Minimize/Eliminate Joints
    - Integral Abutment

        - More Research Needed
        - Discourage Overlays
        - QA/QC During Construction
        - Materials Selection/Proper Use
        - SCC (Self-Consolidating Concrete)
        - High Performance Materials – HPC
        - Design for Inspectability
        - Design for Maintenance
        - Scour Protection
        - Continuity / Redundancy
    - Resiliency
        - Cross Frames
        - Continuous Spans
        - Multi. vs. Single Load Path (track)
        - Failure Modes
        - Engineering Judgment in Detailing
            - Anticipating Movements
- Deterioration Issues
- Preservation Issues
- Preservation Methods
- Deficiencies in Data Collected
- Improve Accuracy of Conditions
- Long Term Monitoring
- Extreme Events
- Corrosion
    - Spalling
    - Delaminations
    - Cracking
- Better Drainage
- Rebar Types
    - Stainless Steel
    - FRP
    - Galvanized
    - Coated Steel
- Fiber Reinforced Concrete (FRC)
- Material selection
    - FRP
    - Admixtures
- Scour
    - Flow Disruption Monitoring

- Materials / QAQC
    - Improvement
- Overload / Collision
    - State oversight
    - Permitting Process
    - Enforcement
- Deficiencies
    - Load information
        - Overloads Permit
        - Overload Link to Deterioration
    - Tracking Action and How Effective They Are
        - Linking Pontis and NBIS
    - Improve Pontis – are Models in Pontis Reasonable?
    - Take Action Inspector’s Recommendations.
    - Inspector Training to Include Peer Exchange
        - Regional Program Exists
    - Rotate Inspection Teams
        - Not use same team year after year
    - Generally Data is Good, Level of Information Adequate
    - Inspectors to Recommend Action & Estimate Costs
    - Grouted Tendons – Assess Corrosion Earlier
- Extreme Events (Collision, Terrorism / Explosive, Nature)
    - Special Scour Inspection
    - Define Lifeline
    - Load Path
    - Assess Residual Material Properties
        - Information to Aid Not Published Together
    - Emergency Inspection
        - Damage
        - What’s remaining
        - Immediate repairs
        - Long term repairs
    - Ability to Re-Open Bridge
    - Way to Alert Public
    - Seismic Information
- Sensor Technology
    - Damage
    - Performance
    - Data for Better Design
    - Construction / Repair Damage

- Early warning
- Damage evaluation
- Which structures monitored?
  - Identify goals
- Global vs. local – different sensors
- Short Term Installation to Collect During Inspection
- Baseline vs. Existing
- Sonar to Monitor Scour
- Long Term Installation → Event Triggers
- Sensor Durability Needs To Be Improved
  - Decrease Cost
- Fiber optics
  - Expensive
- Strain Gages, Frequency Based
- Difficult to monitor for unknown
- Monitor Corrosion
  - Moisture
  - CL-
  - Still developing
  - Install on new construction
- Monitor Load Paths?
- Periodic Calibration of Sensors to Maintain Accuracy
- Minimize post processing
  - System Development
  - Establishing Triggers
- Inspector Training on Sensors
- Passive sensors – RFID [Radio Frequency Identification] type
- Sensors for Unknown Foundation Characterization Needed
  - GPR [Ground Penetrating Radar] Possible?
- Research in Area of Mode Shapes
- Warning Light for Public
  - How Triggered?
- Sensor Bridge to Verify Design Assumptions
- GPS / Video Monitored By Computer
- A/E only for Specific Applications
  - Cable
- Better Communication From Bridge Industry to Sensors Industry of Needs / Desires
- Issue of Liability
  - Sensor Manufacturer / Owner

- Decision making
    - Need to Consider:
        - Costs
        - Politics
        - Recommendations From Inspection
    - Need to Prioritize
    - Planning is Reactive / Not Proactive
    - Lack of Ability to Save Funds For Future Needs
        - Need to Consider
- Rapid Replacement
    - Precast / Prefab / Segmental
        - Superstructure
        - Substructure Also
            - Often overlooked as Area for Precast
    - Agree with idea
    - Will Eventually Become Standardized Pieces if Used Regularly for New Bridges
    - Stockpile Standard Shapes for Emergency Situation
    - Durability of Connections Need Attention
        - Current Study (soon)



- Extreme Event Design
    - Events May Require Opposite "Repair" Techniques
    - Better Planning for Future Needs
        - Don't Upgrade Seismic if Bridge Will Be Replaced in 5 Yrs.
    - Identify Applicable Extreme Events for Given Location/Bridge and Assign Probability/Risk
        - Critical Nature of Structure
    - Informed Management Decisions on a Case-By-Case Basis
    - Combine Projects for Economy
        - Minimize User Costs, etc.

E.4 Cable Supported Bridges

- Material
    - Strength
    - Ductility
- Seismic Behavior
- Multi-Hazard Concept
- Deck Durability
- Cable Durability
- Construction Issues
- Inspection and Monitoring

E.5 Bridge Security

Importance of bridge security 7 years after 9/11?

- The actions of large agencies demonstrate that there are many who consider infrastructure security a high priority.
- Many owners are not convinced that the threat is real.
- We are not designing against attack for the most part.
- Need standards or guidelines in addition to risk assessment. There is much to be done to inform bridge owners that initial investments for security on new designs are not necessarily more expensive. This should be investigated.
- Everything has a cost. We should not focus just on hardening.

New design issues:

- Some incremental initial costs, but survival from attack warrants the investment. These ideas do not "break the bank."
- Must be done at the initial concept stage (the environmental stage, when purchasing real estate).
- What is the performance that we expect? What are we designing to resist? Are there ways to be creative in addressing the issue of how large a blast to resist?
- Consider low-cost issues. Need list of security design elements; need detailing examples.
- Design issues – bread and butter bridges – governed by ability of computer programs, etc. to design according to several risks.

Issues with existing facilities:

- There are many concerns with protecting security information (operational procedures, plans, even structural enhancements).

- Rapid replacement must be brought to the front. Risk analysis, reliability must drive the process. This also goes to the ability to respond and recover from events as the first priority. The things that work for new structures are not possible for existing facilities.

Risk-based Approach:

- Security for existing facilities is multi-pronged: 1st be able to Respond and Recover; Deny, Deter, Detect; Defend—4D's—(standoff and hardening). These concepts are easier to apply to new bridges. For both these requires component-level risk management (prioritizing security projects to fit limited budgets). Large bridge security is very expensive, so we have no choice but to use a risk management approach that allows owners and operators to make informed decisions that fit political, social and strategic agendas. This is a multi-hazard approach.

Multi-Hazard Issues:

- All hazards must be evaluated alongside any hardening projects that might have an adverse effect, i.e., earthquake.
- Preparedness must begin in early planning stages. Must have a multi-hazard risk assessment in the planning stage.
- Multi-hazard approaches are complicated, difficult to link. This must be done technically, not politically.
- Multi-hazard: includes all security issues – blast, fire, cutting, etc. – but can't consider any of this unless we first consider other bridge issues such as seismic. Then owners decide on what type of risks they can accept – and other political / social agendas.

National Policy Issues:

- National standards seem to focus on existing as opposed to new facilities. We need to be sure that we understand and work within the constraints of these policies. Should we inform policy?
- What is the relative priority for existing vs. new facilities? Should we be taking a multi-hazard approach in which security is one of many threats (alongside corrosion, earthquake)?
- What about the multi-modal and multiple infrastructures that must be considered within any strategic plan. Redundancy for the entire system must be balanced, sensibly, with a multi-hazard approach, understanding the need for renewal.
- Standards: In civil engineering standards come at the end, and this approach is not necessarily understood at all levels of government. Need a rational approach.

- National Response Framework – nation's guide to all hazard response – (homeland security – Jan. 08)

Bridge Inspection Data and Security:

- Within NBI – should we be collecting other information for this system that will help with security related issues?
- No – because this information is publicly available. Don't want any of this information out there.
- Some information should actually be taken out? – AASHTO survey found that most states do not have an issue with the data that is released by FHWA because the data is basically unusable for terrorist acts.
- NBI data release can easily be used to find the most critical bridges, but then is not useful to determine a way to destroy it.
- There is a report on this question – state sponsored project to develop a bridge inspectors checklist on security data to include in the inventory. Not reported to the NBI – just collected for the state. Report should be available from NJDOT research.
- There is a Building Security Council that evaluates buildings for security issues, and the same thing could be done for bridges. The question is really what data is needed.
- It can't hurt to collect this information.

What should be included in our design codes on these security issues?

- AASHTO has not in the past few years included a lot of information on security within the actual specifications. Most of the additions have been general comments. Question is – is it a security issue to release specification on how to design for security issues? Will it have to be a protected document?
- It takes awhile to get things into standards – what we should be asking is: How can we supplement designers' knowledge, but we don't necessarily have to incorporate into actual specifications.
- Possibly come up with performance measures.

Top Issues:

- Over the next few years – come up with structures that include more redundancy – more structural redundancy.
- Standards – we can't keep adding more and more – we will "drown" in standards. Just need to add to the knowledge
- True multi-hazard design methods – not just policy
- Reduce reliance on theoretical / statistical solutions without having true physical knowledge for an overall system.

- Generic, less specific guidelines are available (Eric Williamson); were adopted by AASHTO Bridge Committee.
- Establish performance standards that will lead to standards. The performance standards should come from owners, the engineer can promulgate guide specifications from these needs - Performance-based design.
- Establish classes of bridges: critical and non-critical for which security design should apply.
- Challenge engineers to develop and deploy new solutions to improve resiliency to terrorist threats (high-level redundancy as an example). What is the definition for redundancy for critical structures.
- Resiliency must consider recovery period, since some threats impact a facility irrespective of redundancy (an example is the fire hazard). Standardized design, prefabricated construction methods are already considered by the community, and these ideas can be leveraged for security.

Committee Issues:

- Lack of information; difficulty publishing sensitive information.
- Need to move committee business to resolve these issues.

Summary—What are the priorities for committees and research community in security arena? Where do we need funding?

- Define multi-hazard.
- Funding is limited, and security is not the only consideration for scarce resources. Therefore, we must establish proper multi-hazard risk management process.
- Classify bridges and establish terminology (respond and recover is best approach (perhaps all that is needed) for some classes. Other, more critical facilities require more comprehensive measures.
- Recognize that the 4 D's for bridge security must be linked with the "soft" protective strategies (respond and recover for example).
  - Deny
  - Deter
  - Detect
  - Defend
- Integrate safety and security.
- Structural health monitoring technology can be adopted to security needs; this can work the other way around, that is, use security technology (like intelligent video) in other areas. We should nurture that natural symbiosis.
- Detection is only as good as the response. Operational issues that concentrate on saving lives is a big consideration. Keeping people from entering a facility is

under incident management. Monitoring member condition, as from heat effects from fire, can be useful to improve operational planning and response.

- There is a lot of overlap between the many things we do day to day to manage and operate our bridges and the things we can do to secure structures.
- At the same time, incident commanders responsible for response need to have information from the engineer to effectively manage the response. Must be part of the concept of operations. State bridge engineer need to be part of the command structure for response to bridge collapse.
- Cameras are good for post-event investigation.

APPENDIX F

Question-and-Answer Sessions

Workshop participants were given the opportunity to ask questions following the national experts' presentations and Bridge TAC chairs' presentations on the first day and the breakout reports on the second day. The questions and responses are provided below.

F.1 Presentations to Set the Stage

"Evolution of Bridge Technology" Presentation by Tom Ho

Question: What is the role of "redundancy" in bridge evolution? Would it be a "revolution"?

Response: Engineers have been building bridges and other structures for thousands of years. Throughout history, structural failures have happened during construction or during service life. Through these failures, engineers have learned how to improve design and how to select better materials and more suitable construction methods. Knowingly or unknowingly people learned the limits and started introducing redundancy to structures. Redundancy did not happen overnight; it came through a long and painful learning process. A simple example is that engineers initially had no code, then had allowable stress design (ASD), and today have load and resistance factor design (LRFD). It took many years for engineers to understand loads, material properties, and structural behavior. Engineers gradually learned how to deal with redundancy and factor of safety. Therefore, redundancy is an "evolution" not a "revolution" in the long history of structural design/construction.

"Enhancing Bridge Performance" Presentation by Steve Chase

No questions.

"Technologies for Condition Assessment of Bridges" Presentation by Glenn Washer

Question: How about "reliability," not "risk," in future challenges of NDT?

Response: Risk-based inspection sets frequency of inspections based on the likelihood of a certain deterioration occurring and the risk that poses to the durability or safety of a structure, with the goal of achieving a certain reliability. Risk and reliability are in some ways two sides of the same coin.

Question: What is the role of NDT/NDE in future challenges?

Response: There have been many positive developments in the application of NDE for the routine inspection and maintenance of bridges and highways, but challenges remain.

Implementing NDE within the context of a routine inspection can be problematic because of the time and special training frequently required. For many bridges, visual inspection will provide an adequate condition assessment, based on the risk. For NDE to be implemented more effectively, identification of the structures and materials most at-risk is necessary such that the focus of resources can be placed where they are most needed. In this case, we should think not just of risk of collapse, but the risk to the durability of the structure, to identify deterioration in its early stages so preservation strategies that reduce the effects of the deterioration on the durability of the structure, and therefore extend its service life, can be implemented. There are many new and effective NDE technologies that can be used to supplement and improve condition assessments, finding the right methodologies for implementing these technologies remains a challenge. The implementation of risk-based inspection strategies could greatly increase the application of NDE technologies, by focusing resources where they are most needed.

Question: How do you feel about legislators and policymakers discounting the current visual hands-on inspection techniques currently used?

Response: Visual inspection is the most widely used NDE technique across all industries, and has many positive characteristics, not the least of which is low cost. There is room for improving current visual inspection capabilities, many dealing with quality assurance and training of inspector to ensure consistent and reliable results. I think it is unlikely that we will ever find a suitable replacement for visual inspection; NDE and bridge health monitoring should be viewed as tools that can be utilized to supplement and improve visual inspections. But visual inspection is the fundamental inspection technology as NASA, in the power industry, etc., NDE is a tool utilized in circumstances where visual inspection has been identified as inadequate to achieve the desired results.

Question: When the states were surveyed, they said they need easier to use, easier to interpret, cheaper, and safer inspection methods. Will current research provide what the states are requesting?

Response: I think that there are many technologies available now that can meet these needs; the primary challenge is developing implementation strategies that fit within the context of bridge inspection. It is true that there remains a gap between the training required to implement many NDE technologies and the training typically specified for bridge inspection personnel, and this will likely remain as long as there is such a high demand for routine inspections. Developing standards for specialized inspections, improving training and education available, identifying the correct application of NDE technologies and clarifying accurately what should be expected from these technologies can assist in this process. One example is infrared thermography, which on a certain level is a complex technology, but can be reasonably and rapidly applied with a modest level of specialized training, has ruggedized equipment available and provides real-time results. This is a technology that can supplement visual inspection, but the limits of the technology have to be understood such that expectations are consistent with the capability of the technology. A pooled fund with Texas, New York and Missouri is currently working on this issue, identifying the necessary conditions for inspections, what results should be expected, and testing the technology in the field to identify implementation challenges. More research of this type is needed to further develop the appropriate methodologies for implementing NDE.

"Overview of the FHWA's Long Term Bridge Performance Program" Presentation by Hamid Ghasemi

Question: For many owners, applying a monitoring system on a bridge is a ticket for immediate attention of a bridge. How are you planning to tackle this issue?

Response: For over a decade, the FHWA has been seriously looking into using tools and sensor technology for condition assessment of highway bridges to compliment visual inspection. In my opinion, there are still many challenging issues that need to be addressed before routinely applying monitoring systems to our bridges. These are related to longevity, durability, accuracy, ease of use, cost, etc. It is also important to recognize that owners need reliable methods for interpreting sensor data into useful information/knowledge in a timely manner. This may be the most challenging issue for applying any monitoring system to bridges.

The good news is that the FHWA Long-Term Bridge Performance Program (LTBPP) has potential to address the concerns stated earlier. We are planning to conduct detailed inspection and monitoring of a large number of bridges nationwide utilizing sensor technology in addition to visual inspection. The outcome can provide a better understanding of what is out there and what technology really works. I am confident this program will provide owners the information they need to make a better decision about managing bridges.

F.2 Presentations by Bridge TAC Chairs

Steel Bridges Committee Presentation by Chair, Reagan Herman

Question/Comment: I-35 collapse in Minnesota seems to be because of a gusset plate problem. Are other similar bridges in immediate danger?

Response: Inspectors aren't required to measure plate thickness. Once a bridge is in place, it is assumed to be safe. We cannot ignore the fact that it was a poor design. However, fatigue issues received lots of publicity. The importance of taking a look at the bridge system before doing any major work has also become clear.

Question/Comment: Inspections of I-35 Bridge in Minnesota were going on till June 2007 and collapse occurred in August.

Response: The collapse wasn't a deterioration issue, rather a poor detailing. The engineers didn't use right size gusset plates. This issue isn't addressed through inspections, since inspectors don't measure thickness of gusset plates.

Question/Comment: Weathering steel is not good in marine environment. Why are we using it?

Response: Single solution may not be possible for all projects. However, coating is a good answer to address these issues.

Question/Comment: Are fatigue and corrosion material issues? How much does corrosion contribute to fatigue?

Response: Fatigue is a detailing issue. Corrosion does develop near joint details because of moisture accumulation. Naturally, they increase each other. We can improve fatigue behavior by reducing corrosion.

Timber Bridges Presentation by Chair, James Wacker

Question/Comment: Is there any reliable research or model that relates moisture to deterioration rates or durability?

Response: Yes, there are several studies that that report on in-ground wood test stakes at several "severe-decay" zones around the US. However, that does not always represent the exposure conditions in the highway bridge environment very well.

Question/Comment: How many timber bridges are constructed each year?

Response: In the past, there was steep increase in construction of timber bridges. However, during last 5 years, there have been less than 1000 timber bridges per year.

Question/Comment: How much moisture can timber absorb?

Response: It depends on timber species, but a small amount of moisture absorbed in a vulnerable location can exceed the threshold level (~25 percent) for decay to commence.

Question/Comment: Durability depends on new construction with better material. Can impregnation of wood by polymers to reduce moisture be effective?

Response: Polymer impregnation of wood is certainly helpful and is done in synthetic wood members. Some current work is focusing on this approach to enhance the durability of timber bridge components.

Question/Comment: Your presentation was focused on superstructures. What about substructures?

Response: From deterioration stand point, observations made for superstructure apply to substructure also. However, exposure level is more severe and it is an issue. Amount of preservative required is high for substructures. However, durability of substructures is a key issue.

Question/Comment: Is the use of sensors from performance measure and cost points of view justified?

Response: Certainly sensors and monitoring are not economical. However, our efforts are focused on the type of data we want to collect 10 years from now.

Concrete Bridges Committee Presentation by Chair, Nur Yazdani, and Danielle D. Kleinhans

Question/Comment: 95% of primary element condition ratings for individual bridge components will vary within two rating points of average. Where does this statement come from?

Response: This is based on "Highway Bridge Inspection: State-of-the-practice Survey" by Moore, Mark, Rolander, Dennis, Graybeal, Benjamin, Phares, Brent and Washer, Glenn, FHWA-RD-01-033.

Question/Comment: When you say within two rating points, does that mean that five points fall outside?

Response: Yes

Comment: Two rating point average is for the distribution. Otherwise, it is not possible to have 68% vary within one point.

Question: What causes transverse deck cracking every few feet?

Response: While transverse deck cracking could be caused by shrinkage, there are many other variables in concrete mixes that could cause it. Quality control is a big issue; we must have quality control to have a viable bridge.

Bridge Management, Inspection and Rehabilitation Committee Presentation by Chair, Sreenivas Alampalli

Comment: Enforcement of overload is a major issue. An estimated 30-40% of overloads are not stopped.

Response: Yes. It is major problem. NYSDOT has initiated a project on overloading. In this project, we are going to select a corridor and instrument bridges to monitor overloading.

Comment: There is a major change to NBIS 2005: "All divers have to be trained in FHWA approved course".

Comment: At waterline, we have problem of corrosion and deterioration and difficult to distinguish between them.

Cable Supported Bridges Committee Presentation by Chair, Khaled Mahmoud
Question/Comment: Were the cables of the Clyde Arch bridge in your presentation damaged because of a hit?

Response: Not sure if it was the case.

Comment: I suggest that if the anchorage area is protected, you are well ahead in protecting the structure.

Response: Japanese have done been leading in protecting anchorage of cables in bridges. Dehumidification system is best in preventing degradation of steel wires. You are circumventing degradation by taking moisture out.

Question/Comment: Before the Northridge earthquake, steel connections were based on simulations of earthquakes including statistical analysis. Then the earthquake hit and we learned the lesson that most of the statistical approaches were in the wrong direction. My concern is that all the statistical samples and assumptions are based on laboratory testing and limited observations of very small samples. How concerned are you with a potential repeat similar to the Northridge disaster? Could there be something that was missing in the global system?

Response: Application of statistics and probability can be given a wrong name by comparing with seismic case. We have limited data. We are bound to use it. Of course, there is a margin of error. Probability analysis is the best option based on tools that we have.

Bridge Security Committee Presentation by Chair, James C. Ray
No questions.

F.3 Breakout Session Team Reports – Chair Panel

Question: Where do you put substructures, e.g., scour? How are we going to make sure hydraulic channel concerns will be included?

Responses:

- These areas were covered in the 2005 Hydraulics and Geotechnical Conference.
- Data collection on types of bridge failures is needed.
- Although hydraulics was not the focus of this workshop, hydraulic and geotechnical engineers did participate.

Question: What do we want to come out of this workshop? We had breakouts with different scopes and directions in each.

Response: The purpose of the workshop is to work toward enhancing bridge performance, specifically related to deterioration. I believe this was discussed in each breakout group, but we will have to evaluate the results and determine the outcome.

Comment: There is a difference between condition/performance and safety. Safety wasn't addressed. If we inspect condition deterioration, that's different from safety. The difference needs to be made clear. Good condition doesn't always mean good safety, and vice versa. We don't know about traffic load, etc. We need to consider performance measures for condition and safety separately. More discussion is needed.

Question to each panelist: In your opinion based on what you've heard and seen here, what is your topmost statement of concern?

Responses:

- We are way under-funded.
- Attention to detailing regarding deterioration, e.g., moisture control of timber bridges. We need to invest more up front in design, construction, and fabrication.
- Concrete deterioration issues need to be detected early
- Identify critical details and put attention there.
- Compile all knowledge into a central database to share with all.
- A multi-hazard approach is necessary. Past bridge security efforts have typically been narrow. We need to broaden these efforts to a consistent multi-hazard

approach. For example, what we're doing for structural health monitoring can help on the security side, and vice versa.

- From 1971 we have come a long way. There is still room for improvement. More focus is needed on ductility. We are headed in the right direction, e.g., with the FHWA Long Term Bridge Performance Program.

Question/Comment: Public perception is that the infrastructure is important. We need to take advantage of this visibility. Discussions here can contribute to address funding before another collapse.

Response: Funding is always an issue. The purpose of the workshop is to address technical issues, e.g., what we need to measure to determine true performance. We need to outline the important areas to look at, to provide guidance, and then request funding.

Comment: There are two types of fiber-optic sensors: one is continuous and costs less than 50 cents per foot, the other is discrete and expensive, e.g., grating at $30-50 each. The continuous-type sensor gives information along the entire length. Another issue is the interpretation of sensor data to obtain something useful to engineers; some sensors don't need interpretation. We need to distinguish between continuous versus discrete sensors when discussing future monitoring.

Comment: After the Schoharie Creek Bridge collapse in 1987 the NYSDOT did a survey of failures since 1950 and found scour to be most critical. That resulted in the development of six hazards, with security recently added. If we collect more data, what will we do with it? We need to use what we have more effectively and ask whether the data will improve conditions. We need to look at what decisions need to be made to enhance performance. We need to target the critical elements and evaluate how we can increase service life.

Question: How would you summarize your observations from the workshop, and what are our next steps?

Responses:

- This workshop provides input to ASCE and FHWA on where to concentrate from the participants' perspective. This workshop is to provide the technical direction and issues, and where the ASCE/SEI Bridge TACS need to step next.
- We need to look at the evolution of bridge technology and what's available now.
- Good guidance is needed on how we can determine the true condition of our structures.
- We learned priorities, many focusing on maintenance and its associated issues, e.g., structural health monitoring, new coatings, protection of bridges. The data

collected here should be utilized as the consensus of professionals on maintenance and maintenance needs.

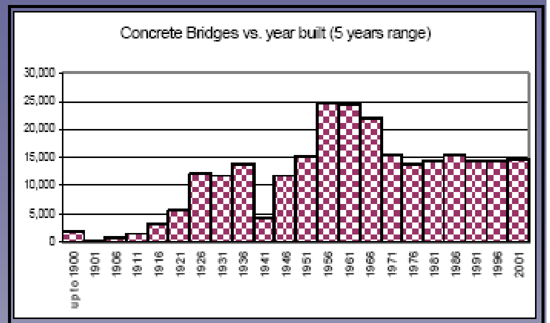
- We need a mechanism to improve things. We need an effective way to educate and communicate information so that we don't do the same things over and over and keep repeating mistakes.
- Decision-makers in the states need to be in a position to make informed decisions. The transfer of knowledge is not expensive, but it is not happening.
- Improvements in our communications and transfer of technology are needed. Our client base is the state DOTs. Engineers from the state DOTs need to be attending conferences to learn the latest available technologies. However, state DOT engineers are frequently not allowed to travel out of state, even when travel expenses are reimbursed. More electronic conferences are needed, e.g., webinars and videoconferences.
- Bridge inspectors should have some type of rotation aspect to their continuing education. We need the best and brightest inspectors because problems with quality control (building according to design) will continue to be a challenge. Inspectors can teach much to designers and need to be rotated through design, and vice versa.
- Participants were encouraged to send in additional comments on needed Bridge TAC direction.

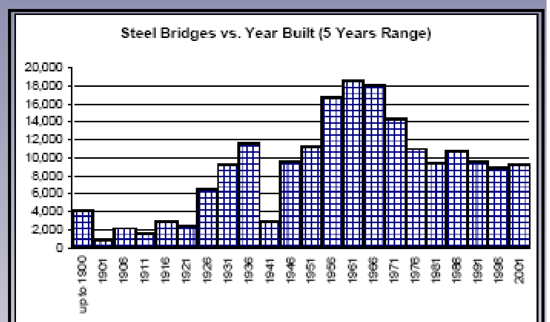
APPENDIX G

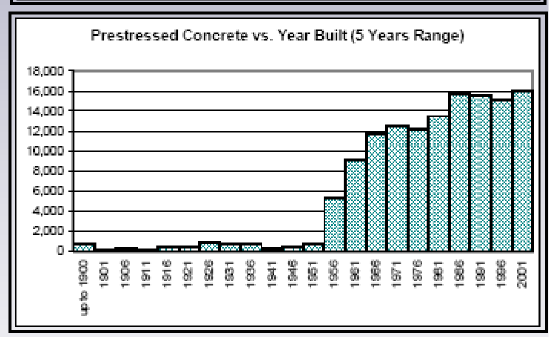
Selected Datasets - National Bridge Inventory (Source: FHWA)

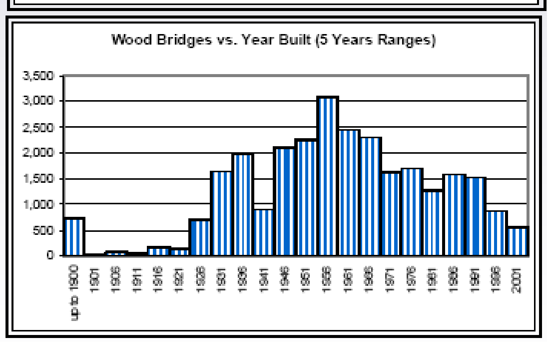
Count of Bridges by Material Type and Year Built

Year built	Concrete	Steel	Prestressed Concrete	Wood
Before-1900	1,738	4,196	642	731
1901-1905	283	825	126	34
1906-1910	882	2,129	222	69
1911-1915	1,556	1,597	161	47
1916-1920	3,248	2,899	381	182
1921-1925	5,564	2,395	403	152
1926-1930	12,121	6,529	852	716
1931-1935	11,874	9,255	752	1,650
1936-1940	13,883	11,566	657	1,994
1941-1945	4,463	2,949	198	898
1946-1950	11,824	9,509	418	2,121
1951-1955	15,185	11,268	728	2,255
1956-1960	24,584	16,684	5,278	3,090
1961-1965	24,345	18,621	9,176	2,453
1966-1970	22,017	18,002	11,709	2,309
1971-1975	15,333	14,304	12,513	1,631
1976-1980	13,801	10,990	12,195	1,701
1981-1985	14,186	9,321	13,510	1,286
1986-1990	15,409	10,742	15,685	1,589
1991-1995	14,265	9,611	15,580	1,534
1996-2000	14,500	8,845	15,178	870
2001-2007	14,545	9,275	15,977	568





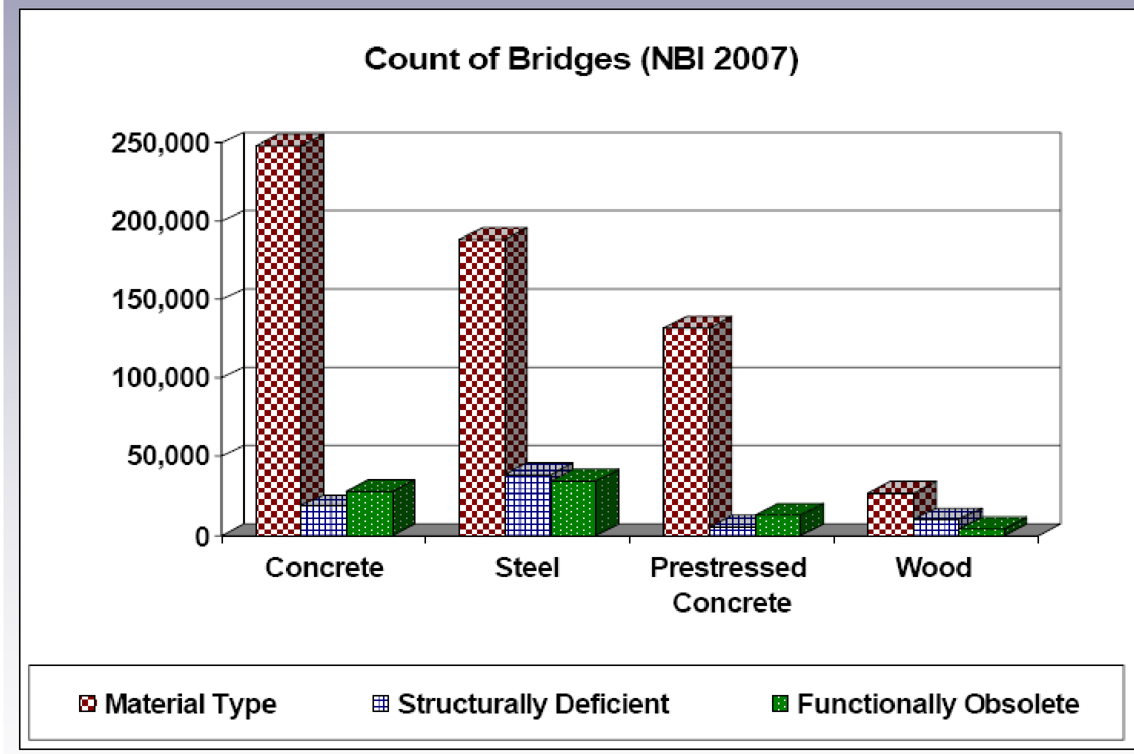




Count of Bridges by Material Type and Deficiency

Count of Bridges	Concrete	Steel	Prestressed Concrete	Wood	Others*
MATERIAL TYPE	248,739	188,551	132,033	26,682	3,802
STRUCTURALLY DEFICIENT	18,506	38,419	5,036	9,855	710
FUNCTIONALLY OBSOLETE	28,187	34,678	12,773	3,482	685

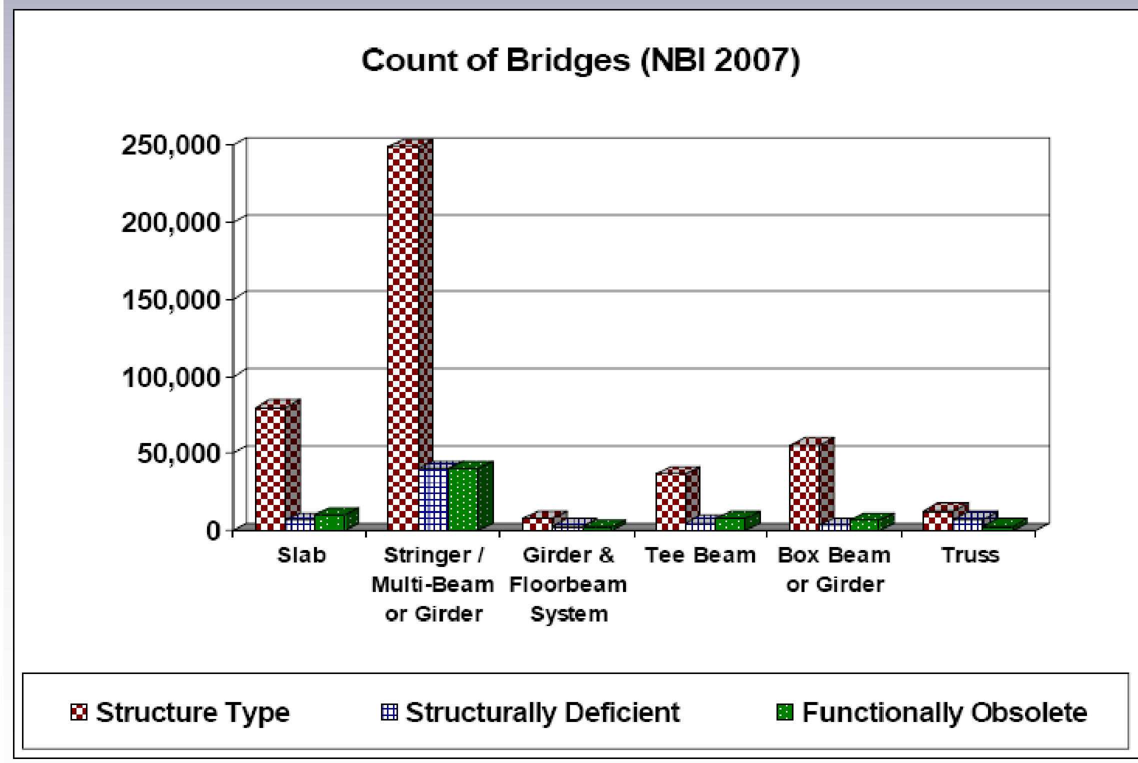
* Includes: Masonry; aluminum, wrought iron, or cast iron; and other



Count of Bridges by Structure Type and Deficiency

Count of Bridges By:	Slab	Stringer /Multi Beam or Girder	Girder & Floorbeam System	Tee Beam	Box Beam or Girders (Single or Spread / Multiple)	Truss- (Deck & Thru)	Suspension/ Stayed Girder	Others* (Culvert)
STRUCTURE TYPE	79,879	249,238	7,432	36,444	55,330	12,608	133	158,726 (126,401)
STRUCTURALLY DEFICIENT	6,600	39,911	2,594	4,770	3,189	7,161	36	8,262 (2,944)
FUNCTIONALLY OBSOLETE	9,612	39,819	1,792	7,807	6,660	2,455	44	11,609 (5,543)

* Includes: Frame; orthotropic; arch-deck & arch-thru; movable (lift, bascule, and swing); tunnel; mixed types; segmental box girder; channel beam; other; and culvert



APPENDIX H

Related Websites and References

Related Websites

Accelerated Bridge Construction List, Federal Highway Administration: http://www.fhwa.dot.gov/bridge/accelerated/abclist.cfm

American Society of Civil Engineers: http://www.asce.org

Federal Highway Administration, Turner-Fairbank Highway Research Center: http:www.tfhrc.gov

Forest Products Laboratory, U.S. Department of Agriculture, Wood Transportation Structures Research: http://www.fpl.fs.fed.us/wit/index.html

Hazard and Security Activities of the Transportation Research Board: http://onlinepubs.trb.org/Onlinepubs/dva/SecurityActivities.pdf

High Performance Concrete, Federal Highway Administration: http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home

High Performance Concrete, National Concrete Bridge Council: http://www.nationalconcretebridge.org/hpconcrete.html

High Performance Steel, Federal Highway Administration: http://www.fhwa.dot.gov/bridge/hps.htm

High Performance Steel Bridges, American Iron and Steel Institute: http://www.steel.org/AM/Template.cfm?Section=High_Performance_Steel&Template=/TaggedPage/TaggedPageDisplay.cfm&TPLID=34&ContentID=9196

Long-Term Bridge Performance Program, Federal Highway Administration: http://www.tfhrc.gov/structur/ltbp.htm

National Bridge Inventory (NBI), Federal Highway Administration, http://www.fhwa.dot.gov/bridge/nbi.htm

National Bridge Preservation Workshop (April 17-18, 2007):

- Lessons Learned: http://www.fhwa.dot.gov/bridge/preservation/action02.cfm

- Workshop Action Register: http://www.fhwa.dot.gov/bridge/preservation/action03.cfm

- Bridge Preservation Research Topics: http://www.fhwa.dot.gov/bridge/preservation/action04.cfm

Prefabricated Bridge Elements and Systems, Federal Highway Administration: http://www.fhwa.dot.gov/bridge/prefab/index.cfm

Structural Engineering Institute (SEI) of the American Society of Civil Engineers: http://www.seinstitute.org

The Bridge Preservation and Maintenance (BPAM) Roadmap (Draft 3/28/2007) http://www.fhwa.dot.gov/Bridge/preservation/roadmap2007.cfm

Wood Education and Resource Center, U.S. Department of Agriculture, Forest Service, : http://www.na.fs.fed.us/werc/

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The Federal Role in Highway Research and Technology, Special Report 261, Transportation Research Board, National Research Council, Research Technology Coordinating Committee, 2001, http://books.nap.edu/openbook.php?record_id=10222&page=1

Timber Preservation Treatments for Highway Applications, Tech Transfer Summary, by Bigelow, Clausen, Lebow, and Greimann, Bridge Engineering Center at Iowa State University and U.S.D.A. Forest Products Laboratory, October 2007, http://www.ctre.iastate.edu/pubs/t2summaries/timber-preservation.pdf

(Note: The full report is a field manual entitled "Field Evaluation of Timber Preservation Treatments for Highway Applications")

Transportation System Preservation Research, Development, and Implementation Roadmap, U.S. Department of Transportation, Federal Highway Administration, January 2008, http://www.tsp2.org/roadmap/exec.pdf

Wind-Induced Vibration of Stay Cables, by Kumarasena, Jones, Irwin, and Taylor, Report No. FHWA-RD-05-083, Federal Highway Administration, August 2007, http://www.fhwa.dot.gov/bridge/pubs/05083/05083.pdf

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