A Problem-Focused Agenda for the Highway Transportation Infrastructure: A Holistic Systems Identification and Integration Approach Using Field Test Sites

Final Report of Workshops Held

By

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1. Introduction

The highway transportation infrastructure is an excellent example of an intertwined hyper-system, that is, a system-of-systems. It includes a large variety of both constructed and manufactured engineered elements, a wide spectrum of embedded human, organizational and social systems, natural elements such as soil and water, and broad impacts of nature on the system. The hyper-system is affected by very dynamic phenomena such as traffic accidents and earthquakes, as well as extremely slow events such as material aging and deterioration. In addition, the contiguous elements of the highway transportation system represent one of the largest geographic scales of any engineered system. The highway transportation system connects, both physically and by the users, to all other transportation systems and the remaining critical infrastructures. A coordinated research and demonstration program that would focus on the highway transportation hyper-system would offer both system-specific returns as well as great generic payoff in knowledge and insight for advancing the engineering and management of all infrastructures.

Historically, the design, construction, maintenance and operation of the highway transportation infrastructure system have been greatly fragmented. This is evident in practice, research and education. The intersections, interactions and cause-and-effect relations between the engineered, human and natural subsystems are not well understood, or for that matter defined. As we move through the 21st century, the challenges of a deteriorating highway system and limited funds for repair and restoration of existing systems begs for a new holistic approach to the problem. To meet this need the authors propose development of an Engineering Research Consortium Initiative (ERCI). The ERCI would provide coordinated administrative support for a national, integrated research program on the highway transportation infrastructure hyper-system. The cornerstone of the ERCI would be field laboratories, consisting of actual systems and structures. It is only through the investigation of these real systems and structures and how they interact can significant advances be made.

The Federal Highway Administration (FHWA) and the National Science Foundation (NSF) both play key roles in advancing the state-of-the-art and -practice of the engineering and management of the highway infrastructure system. The two agencies offer a set of complementary resources that would very much enhance the Nation's capabilities for scientific research and demonstration projects to advance the engineering and management of infrastructure systems. Each has a unique mission: NSF, to fund high-risk, cutting edge, fundamental research; FHWA, to support and conduct problem-focused research on a national level related to the highway system. A coordinated collaborative research initiative, supported by both agencies would ………..

Two workshops were recently held to bring together a group of multi-disciplinary experts to discuss and frame the problem and to articulate the issues. This report summarizes the results of these workshops. In the following is presented an overview of the proposed Engineering Research Consortium Initiative (ERCI), an overview of the two workshops, and the conclusions and recommendations that arose from these activities.
2. Overview of the Proposed Engineering Research Consortium Initiative

The goal of the ERCI will be to provide administrative support for a coordinated, national, integrated, problem-focused research program on highway transportation infrastructure. A draft organizational structure of the ERCI is shown in Figure 1. Leadership for the ERCI would be provided by a Director and Executive Committee. An Oversight Committee with representatives from NSF, FHWA and other government, academic and private organizations would advise the Director and Executive Committee. The cornerstone of the ERCI would be field laboratories. Most of these sites would be in the United States but there would also be international sites. The field laboratories would be connected in realtime so that researchers and practitioners from around the country and the world can share data and information. Research activities and the field sites would be coordinated under the Research Coordination Committee. The ERCI would also support training and educational activities. An important element of the Center would be the international nexus to collaborators from around the world. Base funding for the ERCI would be provided FHWA and NSF; additional support would be sought from local, state and federal agencies, public and private organizations.


The first workshop was held on Sunday, September 14, 2003 at the Hyatt Rickeys hotel in Palo Alto, California. The meeting was held in conjunction with the 4th International Workshop on Structural Health Monitoring, which took place on September 15 through 17 on the campus of Stanford University.

The workshop was called to order around 2:00 pm and adjourned at approximately 5:00 pm. It was attended by close to 50 people, representing academia, government and industry. The agenda, minutes of the meeting and list of participants are presented in Appendix A.

The meeting agenda included three presentations and a period of open discussion. The workshop opened with a presentation by Dr. Steve Chase from the Federal Highway Administration (FHWA), Turner Fairbanks Research Center, on the FHWA long-term bridge performance (“Bridges for the 21st Century”) program. This was followed by a presentation from Dr. Steven McCabe, Program Director from the National Science Foundation (NSF), Division of Civil and Mechanical Systems, on the NSF research programs and the NEES equipment network. A presentation was then given by the authors on the proposed ERCI. This included a discussion of the draft structure of the organization, field test-sites and the possible research agenda for the ERCI. Following the presentations there was time for questions and discussion from the audience. There were a number of questions posed and many thoughtful suggestions provided by the participants.

Important observations and recommendations to come out of the workshop include:
1. There was general consensus among the participants of the need for such an initiative. The benefits that could be derived from an integrated, focused research program, centered on field laboratories could be tremendous.

2. Representatives of the FHWA and NSF see the merit of such an initiative. They also believe there is sufficient common ground in the current research agendas of the two agencies to justify a joint NSF-FHWA research initiative. NSF has been funding research related to bridges for some time. They also have programs in health monitoring, sensors and deterioration science. FHWA is ready to embark on a major new program – “Bridges of the 21st Century.” NSF has partnered with other federal agencies to develop joint-agency research initiatives (the PATH program is just one example).

3. The program would require developing partnerships between academia, government and industry. Since most of the field test sites would be owned by local and state governments and authorities, well thought out agreements that detail access to the sites and access to information would be required.

4. Important issues relating to the organization, operation, and administration of the ERCI remain to be resolved. This includes how test sites would be selected, funding for the sites, the research agenda, how research projects would be evaluated and funded, to name just a few.

5. A good model for the proposed network of field laboratories is the NSF George E. Brown Network for Earthquake Simulation (NEES). The NEES network has many of the features and attributes of the proposed network of instrumented infrastructure sites.

6. There would be benefit to instrumenting existing bridges, both those that are “healthy” and “problematic” bridges, as well as new construction.

4. Summary of the Workshop Held November 12, 2003, Tokyo, Japan

The second workshop was held on Wednesday, November 12, 2003 at the Number 1 Engineering Building, Hongoh Campus, University of Tokyo, Tokyo, Japan. The meeting was held in conjunction with the 1st International Conference on Structural Health Monitoring and Intelligent Infrastructure, which took place on November 13 through 15 at the Japan Society of Civil Engineers, Tokyo, Japan.

The workshop was called to order around 10:00 am and adjourned at approximately 5:00 pm. It was attended by more than 50 people, representing academia, government and industry, and included representative from 9 countries. The agenda, minutes of the meeting and list of participants are presented in Appendix B.
The meeting agenda included a number of presentations and periods of open discussion. The workshop opened with a presentation by Dr. Hamid Ghasemi from the Federal Highway Administration (FHWA), Turner Fairbanks Research Center, on the FHWA long-term bridge performance (“Bridges for the 21st Century”) program. This was followed by a presentation from Dr. Perumalsamy Balaguru, Program Director from the National Science Foundation (NSF), Division of Civil and Mechanical Systems, on the NSF research programs and the NEES equipment network. A presentation was then given by the authors on the proposed ERCI. Again, this included a discussion of the draft structure of the organization, field test-sites and the possible research agenda for the ERCI. Following the lunch break were several presentations from various participants from around the world. The topics ranged from structural health monitoring of bridges and the national research programs in Korea, to the Canadian experience in structural health monitoring of innovative structures, to the European position on sustainable infrastructures, and current status of structural health monitoring of long span bridges in Hong Kong.

Important observations and recommendations to come out of the Tokyo workshop include:

1. There was general support from the international community for collaboration with U.S. investigators on developing the ERCI and establishing the international nexus. There are several international test sites (structures) already that would be ideal candidates to be included in the field network.

2. Tremendous advances have been made in the Far East in structural health monitoring of bridges. Numerous signature long-span bridges have been instrumented, as well as other more ordinary structures. Many are networked and provide real-time data to owners and operators of these structures. Canada and Europe are also fairly advanced in the implementation of structural health monitoring systems on actual structures. There is a tremendous wealth of knowledge and experience in this area in other parts of the world; the U.S. research community should take advantage of this experience, thus the importance of the international nexus.

3. **LOOKING FOR SUGGESTIONS HERE**

5. Conclusions and Recommendations

Based on the feedback provided during the two workshops, the following conclusions and recommendations are set forth by the authors:

1. Defining and measuring performance in the multidimensional space of engineering (technical and economical), human (social, organizational and economical), and nature (environmental, preservation, sustainable) is perhaps the first and most important requirement for integrated asset management of complex infrastructure
systems. Just defining the engineering performance is a great challenge. An ASCE SEI Technical Committee has been formed for this purpose and has been investigating, for several years now, meaningful approaches to defining engineering performance. This committee recognized that we should take advantage of structural reliability theory as a foundation, but extend this to the entire spectrum of engineering performance including functionality and security; collecting sufficient data for its quantification remains a major challenge. This Task can only be accomplished by studying actual infrastructure systems in the field.

2. Maintenance and preservation of aged and deteriorated bridges that are also historic landmarks and still serve as a critical crossing is perhaps the most urgent research need. This is not a responsibility we can just delegate to the civil engineering consulting industry. An academe, government and industry partnership is essential, and the experiences of the commission appointed at Europe to save the Tower of Pizza should serve as an example. In fact, preservation of a major historic landmark bridge that is essential for the well-being of a major metropolis is a problem that very much embodies all of the problems discussed in (1).

3. The US Congress and DOT wish to take advantage of the integrated asset management paradigm and leveraging of technology (especially IT and ITS) to improve transportation performance. One of the most critical barriers to integrated asset management is the disconnection between how we are trying to improve various components of performance: Operational performance (efficiency and safety), structural performance (durability, serviceability, safety, resistance against undesirable failure modes), and homeland security are three broad areas of performance. There may be other characterizations.

4. To apply integrated asset management, first we need to understand how to integrate the language, objectives, constraints and theoretical foundations of these specialty areas for performance into one single multi-objective platform. We have reached the limits of what we can accomplish in engineering and management of the highway infrastructure with the fragmented, non-systems approach we have followed for fifty years.

5. The second critical need is to observe and conceptualize the many interactions between nature, human and engineered system elements that govern the performance and reliability of the highway transportation as well as other infrastructures. Currently we have only a vague sense of many of these intersections, and we have not been able to model most of them. We cannot even reliably model the nonlinear-nonstationary behaviors of just the bridge structures, let alone the many human-nature interactions. The "agent" modeling approaches are excellent but whether these agents can simulate humans is quite unproven.

6. To design our initiative and respond to these two main concerns, we realized the necessity of taking advantage of systems engineering. We also realize that systems engineering as we know it requires considerable adaptation and additional
development to serve the concerns of highways and other infrastructures that are large hyper-systems.

7. To adapt and take advantage of systems engineering for serving the needs of highway transportation, we realize the necessity of observing, conceptualizing, measuring, identifying, simulating and exploring how we may control and optimize the performance of the real highway infrastructure system while it is governed by the interactions between human, nature and engineered elements. This is possible only if we step out into the real world and study the system as it actually performs. Hence, the need for field laboratories as the centerpiece of our initiative.

8. The final ingredient we need for accomplishing the above is coordinating and integrating the rare human experts of each of the above areas into one coherent team. For example, we have brought together some of the best of each respective specialty areas together to formulate the initiative. Shino for systems and homeland security, Dan for asset management, Samer for incorporating the human and traffic elements of the system, while myself and Tripp covering the structural engineering and health monitoring areas. Hamid and Sheila are providing both technical expertise but also covering the administrative and organizational (jurisdiction) aspects. Also note that our delegation at Japan included many complementary experts, such as Dr. Comfort covering organizational behavior and government policy.

6. Acknowledgements

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The authors would also like to thanks the many people who participated in the two workshops. In particular Professor’s Chang and Kiremidjian from Stanford University and Professor Fujino from University of Tokyo.
Appendix A

Minutes of the Workshop Held September 14, 2003
Palo Alto, California
W O R K S H O P  
Cardinal Room 1, Hyatt Rickeys, PALO ALTO  
September 14, 2003, 2:00 - 5:00 PM

A Proposed NSF-FHWA Joint Engineering Research Center: 
Advancing States-of-the-Art and Practice of Engineering and 
Management of the Highway Transportation Infrastructure

A G E N D A

1. Overview of FHWA’s Infrastructure Research and Development Programs, and, 
Details of the Long-Term Bridge Performance Research Program. Potential 
Contributions Anticipated From an NSF-FHWA Joint Engineering Research Center. 
Dr. Steven Chase, Technical Director for Bridges, Office of Infrastructure R&D, 
FHWA.

2. NSF’s Vision and Research Initiatives Related to Critical Infrastructure Systems. 
Potential Contributions Anticipated from an NSF-FHWA Joint Engineering Research 
Center. 
Dr. Steven McCabe, Program Director, Structural Systems and Engineering, NSF.

3. Draft of a Possible Structure and the Principles that may Guide the Operations and 
Research of an NSF-FHWA Joint Engineering Research Center: 
Craig Allred (FHWA), Emin Aktan (Drexel University), Dan Frangopol (University 
of Colorado at Boulder), Hamid Ghasemi (FHWA), Samer Madanat (University of 
California, Berkeley), Tripp Shenton (University of Delaware) and Masanobu 
Shinozuka (University of California, Irvine)

4. Discussion and Future Steps
A Proposed NSF-FHWA Joint Engineering Research Initiative: Advancing States-of-the-Art and Practice of Engineering and Management of the Highway Transportation Infrastructure

Minutes of the Workshop

Date: September 14, 2003
Location: Hyatt Rickeys, Palo Alto, California

Attendees: See the attached list of participants

The workshop was called to order by Dan Frangopol at 2:05 pm. Professor Frangopol welcomed the participants to the workshop. He also expressed thanks to Professors Fu-Kuo Chang and Anne Kiremidjian of Stanford University for helping with the local organizations for the workshop. He expressed thanks to Professor Emin Aktan for organizing the workshop.

Each of the workshop participants introduced themselves.

Dan Frangopol described the purpose of the workshop: to discuss plans for a joint NSF-FHWA Engineering Research Consortium Initiative (ERCI). The workshop was the first of two planned; the other will take place in Japan on November 12, 2003, in conjunction with the First International Conference on Structural Health Monitoring and Intelligent Infrastructure. Dan Frangopol introduced the first speaker, Dr. Steve Chase.

Presentation by Dr. Steve Chase, Technical Director For Bridges, Federal Highway Administration:

Chase would provide an overview of the strategic direction of the FHWA research and development program. The FHWA program has been guided by TRB Special Report 261, the National Highway R&T Partnership and NCHRP 20/07 Task 121.

Chase outlined AASHTO’s Thrust Areas/Business needs for bridge engineering. FHWA’s role is to take on longer term, higher risk, higher payoff R&D; to provide national coordination, to minimize duplication, to encourage synergy, to raise the level for everyone, to promote the delivery of technology, and to push the deployment of new technology.

Chase noted that we want to get out in front of the bridge deterioration curve; we are behind the curve today. In the U.S. there are 160,000 deficient bridges; one out of three bridge crossings made today is over a deficient bridge. Replacement/rehabilitation costs average $7 billion dollars per year. Over 3000 bridges become deficient each year. There is a demand for increased mobility and less congestion; bridges are also vulnerable to attack.
To bring about change Chase identified four elements for success: better educated and trained people, better information about what works, better technology and tools, and deploying new technology.

In bridges the FHWA packages research in three focus areas: (1) bridge of the future, (2) stewardship and management, and (3) ensuring bridge safety, reliability and security.

With regard to people the FHWA would like to establish a few Centers of Excellence, probably within the university system. Centers would deliver the best available technology, develop curricula, would be aware of cutting edge technology. The FHWA would like to see a revitalized and modern demo projects program. There is also a need for a comprehensive suite of NHI courses. The current courses for bridge engineering are inadequate, they need to be modernized to improve the training of bridge engineers throughout the country. The FHWA foresees significant partnerships with industry; a certification program, and technician improvement programs. We need to make effective use of computer based training. Outreach to engineers of the future is also very important: students that are in high school now need to be shown that structural engineering is on par with other high tech careers.

With regard to information, we currently have the National Bridge Inventory (NBI). It consists primarily of element level data. We have done just about everything we can do with the data we have. It is based on visual inspection. The data does not provide the information needed for the next generation of bridge management systems (BMS). We would like to integrate probability and multi-objective optimization into the next generation BMS. We have pushed the envelope in terms of what NDE can do; there are tools that can provide more quantitative data but the information is currently not integrated into the NBI.

A new Long-Term Bridge Performance Program has been proposed. It would identify a representative sample of bridges (in the thousands). Detailed inspections would be conducted of these bridges. The long term program needs to last 20 years or longer. A subset of these bridges (in the hundreds) would be turned into “smart bridges.” One strategic objective of the agency is to reduce the number of deficient bridges to less than 1 in 5. About 26% of the bridges on the national inventory are classified as deficient; 80% of these are deficient for functional reasons, not structural reasons. However, these classifications are based on arbitrary numbers put in place in the 1970’s. The program would provide an opportunity to measure and understand what it takes to make a bridge functionally deficient. There would also be a program of forensic autopsies of decommissioned bridges, that would provide data to feed into models. The data could be used to, for example, understand how much steel is lost over time, to understand the risk of loss of composite action. The resulting database is essential for making informed decisions.

With regard to technology, there is the “Bridge of the future” program. Where material degradation no longer controls, where bridges are built in a fraction of the time and a fraction of the current LCC, where bridges are made to be adaptable, and are immune to
attack, floods, earthquakes and overloads, where vertical and lateral clearances are eliminated. To achieve this goal we must take a systems approach.

With regard to stewardship and management, we need to make sure we have the technology to handle what we already own. There is a need for better inspection; rapid strengthening and repair and restoration methods. The focus must be on maintenance and preservation. Research is needed into deterioration science and control; new technologies must be based in fundamental sciences. We want a BMS that can tell them what to do with a specific bridge.

There is a need for comprehensive decision support systems, with physically based deterioration models. We need performance measures that make sense that we can use to make better decisions about maintenance and preservation. There are also important emerging issues and technologies: homeland security, global warming, assessment of tendons and cables, ubiquitous computing (miniature sensors, etc.)

Regarding deployment, the FHWA is uniquely positioned to push new technologies. Highways for Life – demonstrate what we can do to eliminate congestion, deliver high quality, push things we already know, reduce the time it takes to replace a bridge. We want to change the public’s expectations. To demonstrate that we can deliver high quality systems and minimize congestion. The public demands that this approach be taken. FHWA also wants to redefine the IBRC program, to push risk and to have the states accept higher risk.

Chase finished by discussing how a FHWA/NSF Center would contribute to this vision. The plan compliments the long-term bridge performance program. It compliments the centers of excellence. It would provide a synergistic link between FHWA and NSF missions. It would also leverage resources to achieve shared goals.

Professor Dan Frangopol introduced the second speaker, Dr. Steve McCabe.

Presentation by Dr. Steve McCabe, Program Manager, Civil and Mechanical System, National Science Foundation

Bridges represent a huge national issue. There is a large capital investment when they are new. There is a large capital investment for the operation, maintenance and renovation of bridges. They are essential for emergency services, for a modern economy.

There is an interest in bridges at NSF. NSF has funded research in the seismic performance of bridges, including systems, superstructures, components, and foundations. There are also durability issues, which relates to new materials, new construction methods, sensors, and real time health monitoring. There are issues with security and emergency response.
These issues span the range of what CMS addresses. It is a broad problem that hits on all of the programs at CMS. NSF funds basic, fundamental research, aimed at developing new knowledge. The research is not applied.

Decisions in practice must be made looking at the bigger picture, not just bridges. Comprehensive research looking at bridges as: the keystone of a larger transportation system, dependent on the system and it’s reliability; subjected to multi-hazards. We need to make sure we spend the money on the right problems.

McCabe described NEES, the George E. Brown Network for Earthquake Simulation. It is on par in terms of funding and importance with the NSF polar research program. It is a distributed virtual laboratory. It is everyone’s resource. McCabe showed a slide of all the NEES sites, illustrating the breadth of the facilities.

NEES offers a unique opportunity for truly collaborative research – a new model. It provides a significant new IT infrastructure, where we are able to run experiments remotely. Bridges will be a major topic of interest for the NEES program. There will be many opportunities for research on health monitoring and damage detection using the NEES facilities and through NEES funding.

McCabe outlined the three tiers for funding through the NEES program. Everyone has an opportunity. It is open to only US universities and colleges.

There are three levels of award: Grand Challenge (GC), Small Group (SG) and Individual Investigator (II). The GC can be up to 1.4 million per year. The funding works out to about 9 million per year; most of it is new money. Letters of intent for the first round of funding are due 12/8/03. Full proposals are dues 1/22/04.

There are to be “Payload projects.” GC or SG proposals must test payload components (mechanical, control, sensing, structural or nonstructural components that may detect or support operation of the overall system). The Payload project may be brought in at the beginning or funded separately later.

Some key features to GC projects: there must be experimental and analytical components, and it must have a diverse project team (geography, gender, race)

All of the data from the NEES projects must go to the University of Illinois data repository. This could be the beginning of a true national data archive.

McCabe discussed possible international collaborations; provided examples of NEES research possibilities; noted reports on the NEES program.

What’s the possibility here, for an NSF and FHWA partnership. We may have a model that we can use in the NEES program. Developing partnerships is one primary goal of NSF. CMS is open to some form of joint solicitation. The effort could focus on, for example, durability, seismic performance, security, sensors or health monitoring.
This would have to be a multi-year program. It would take at least 3 million a year to make it worth it, but probably need more than that. It would be jointly funded. It would also mean bringing in interested DOT’s, perhaps somehow related to pooled fund studies. Use a NEES-like approach: basic research, to real applied work.

There are opportunities for international partnerships in research. NSF is currently working on MOUs between NSF and colleagues in Japan and Europe.

NSF’s goal is knowledge creation. By doing this the style of the Engineering Directorate is preserved. We must also preserve FHWA’s needs.

The parts are already in place at NSF and FHWA. We are already doing bits and pieces of this. We don’t have sufficient funds individually. A coordinated effort, with a solicitation that has the words bridges, transportation system, structures, will get peoples attention.

_Dan Frangopol introduced Emin Aktan._

_Aktan_ provided an overview of the proposed joint NSF-FHWA ERCI. Field laboratories would be the anchors for whatever is proposed. The connectivity is the same as in the NEES program. _Aktan_ described the proposed organizational structure of the ERCI. The field labs are the key; these are analogous to the NEES facilities. He described how the ERCI would contribute to the FHWA long-term bridge performance program; it could, for example, lead the way in determining what kind of inspection data is best; develop protocols for inspection. It would integrate and synergize many of the elements of research funded by NSF and FHWA related to the transportation infrastructure.

_Aktan_ described the field labs, or test beds in more detail. The labs must consider the human, natural and engineering elements together. The lab could be at the design, construction, operation, retrofit or decommission stage. He showed examples of possible field labs: an elevated highway in Tampa, Florida; the Hoover Dam Bridge; New York City East River bridges; a collection of ordinary bridges in Pennsylvania; a network of bridges in Colorado; the Honshu-Shikoku bridges in Japan.

_Aktan_ turned the presentation over to _Samer Madanat._

_Madanat_ discussed systems engineering and how it would relate to the ERCI. Some fundamental issues were described that could be addressed by the ERCI. This included modeling and analysis of hyper-systems; identification and simulation of interconnections of hyper-systems; observing and measuring elements in real-time; visualization and interpretation of measured data; intelligent materials, components and systems; affect of uncertainty on system performance and life-cycle costs.

_Tripp Shenton_ briefly discussed issues related to constructed systems, that could be addressed by the ERCI. This includes evaluation of structural condition; damage
identification; system reliability and redundancy; fatigue; design for improved serviceability and durability; multi-hazard mitigation; effective maintenance and repair; health and performance monitoring; advanced materials.

Madanat continued with the discussion of operations issues, traffic operations research and transportation management systems.

Dan Frangopol discussed issues related to integrated asset management. He discussed asset management, the limitations of current BMS, and theory and application of LCC. He also addressed recent advances and research needs.

M. Shinozuka discussed issues related to homeland security. This included discussion of the WTC attacks, the east coast blackout of 2003, simulation of traffic network breakdown due to an earthquake. He also mentioned the application of remote sensing, an important tool for homeland security. Finally, he discussed work being conducted on using SAR for remote and close-range sensing.

The floor was then open for questions and discussion.

A short presentation was given by Mr. Calvert from Blue Road Research about the Broadway bridge in Oregon. The bridge is an old bascule bridge. It is 5 spans and ¾ mile long. They will be instrumenting the bridge with fiber optic sensors (40 in total). It is the third bridge they have instrumented. There are two areas of interest: the lift span/lift mechanism and the composite deck. The monitoring is nominally to last 5 years. Calvert concluded by indicating the difficulties in interacting with the government as they work on the bridge.

E. Aktan noted that there are a lot of important issues that relate to partnering with academe and government.

K. French asked, how would the field labs be funded? Who was to have access to the data? Did a certain person or group have access to the data?

E. Aktan suggested that the answer might lie in the NEES initiative.

S. Chase noted that in his experience, owners have a certain liability. They would want to know what is going to be done with the data and information collected. This would have to be addressed in the agreements with the DOT’s, the owner of the bridge.

E. Aktan continued by noting that you would approach a DOT, develop a partnership and then convince the reviewers that the infrastructure is available. The number of field labs would depend on the funding and the number of proposals.

S. Glaser commented that NEES is not the panacia. The money might have been of better use going other places. He noted the tremendous administrative burden of NEES and the funds needed to support it. He asked how we are going to fight that?
E. Aktan responded by saying that there would be few bureaucrats, administrators; there would be no incorporations. The bulk of the funding will go into the field laboratories and researchers. FHWA and NSF will want the funds to go to research. We must be sensitive to this. However, any effort must be coordinated.

A representative from Pure Technologies asked how decisions would be made on where the funds were to go?

E. Aktan replied that there would be an Advisory Committee, put together by NSF and FHWA, that would oversee the selection of the labs. There would be a peer review process. It would be a very transparent process.

S. Glaser asked if the people on the panels wouldn’t be able to get funding, as with the NEES program.

E. Aktan suggested that we don’t want to adopt all the details of the NEES program.

K. Frank commented that there was no mention or emphasis on input data. We need weigh in motion data and data on the weather. He noted that you must know the input parameters if you are going to study deterioration. This must be done at each site. He also noted that access is a big issue. The cost of closing down a lane of traffic can be significant. He suggested that the biggest problem an owner faces in turning a bridge over to researchers will be user costs (the costs to the public to the public caused by disruption of traffic). He suggested that is might be better to build a new bridge which could be designed to provide easy access (could be at grade) and have instrumentation placed in the structure during construction rather than instrument an existing bridge.

K. French added that if you have new construction it might be cheaper.

E. Aktan commented that both modes are very possible (new construction and existing bridges).

R. Itani would like to know the mechanism for accessibility. Are proposals going to go to FHWA and FHWA would send them to the center?

E. Aktan responded that the center would not be outside of FHWA and NSF. The proposals would be approved by these agencies. There would be no additional layers of bureaucracy. However, we need to coordinate the sites, discuss how a potential new site adds value.

H. Ghasemi noted that not all of the details regarding the ERCI have been worked out.

J. Garrett commented on the importance of collaborations between researchers in IT and those who are developing the field laboratories.
E. Aktan noted that a field lab that looks at a new structure, or several, and designs these structure so that they serve as good field labs would be very valuable, it would answer a lot of questions we have.

A representative from Pure Technologies noted that all of the bridges they have monitored have problems; existing bridges are very important and should not be eliminated from consideration.

A representative from Blue Road Research commented that you must know what the end user wants.

A. Kiremidjian asked, if the decisions for funding were going to be made by NSF and FHWA, what was the center going to do?

E. Aktan first commented that this was to be a consortium, a collaboratory, a connection of a number of different research test beds. If I can strike a partnership with government, I propose a field lab, if I leverage industry support, the review process will consider all of these things.

A. Kiremidjian asked, how was the center going to function? What is the objective of the center? There are different options.

E. Aktan noted how the sites would be connected, how the network would be created

A. Kiremidjian suggested that what we are hearing is a mini-NEES.

E. Aktan noted that the general concept of NEES has attractive elements. There will be several other chances to provide input before the final report is finished.

M. Wang noted that if the funding level is 16 million, you need congressional approval. We need to think bigger about legislation.

E. Aktan commented that we will need to find additional sources of funding. If there is a partnership realized, and an initiative, that is the first step to other mechanisms. We don’t need to come up with 100 million dollars to proceed.

A representative from ISIS Canada suggested that we need to step back a bit further, think about what areas of research, come up with some ideas, with certain themes, you must have a coordinated research program, a wide range of coordinated research, progressive research. You need to take the core that you have and build on that. To get the real results, it has to be coordinated. Coordination is a key factor.

A. Mehrabi asked about incorporating on-going projects? He also asked about the composition of the executive committee.
E. Aktan noted that there has to be participation from government, academe and industry, that the breakdown depends on many factors. Regarding existing projects, if they have desirable attributes they would be good candidates.

K. French likes the idea of coordinated themes.

K. Frank emphasized the importance of trying to reduce inspection costs. The center needs to make sure this is a goal.

D. Lee asked about pavements and whether the new legislation has new funding in this area.

S. Chase responded that the funding includes the long-term bridge performance program. Current pavement funding stands at 15 million dollars a year. He expects the scope in bridges to be about the same.

D. Houston commented that it seems like we are suffering from a sales problem. If we look at the losses from 9/11, the blackout, etc. If we just took a fraction of the money lost from these events and applied it to research, we could fund this effort and many other researchers. There seems to be a disconnect, we are not really selling it, there seems to be something missing.

E. Safak commented on the advanced national seismic system. It involves 1000’s of structures to be instrumented. The last few years it has been getting only 3-4 million out of an expected $10’s of Millions. Consequently, the new initiative is being postponed.

A participant asked what was the time line for the initiative?

S. Chase commented that FHWA is waiting on the Congress to make up its mind about the reauthorization. There is language in the bill that requires congressional action to reauthorize FHWA. Congress has to take some definitive action before the end of September. Congress is talking about a possible 6 month stop gap measure. Things are a little uncertain at this time.

E. Aktan noted that optimistically, it might be November.

S. Chase suggested that it might be sometime next year.

D. Lee asked, if funding is not approved, is the program dead?

E. Aktan noted that this depends on both parties (NSF and FHWA).

S. Chase commented that the level of support is uncertain at this time, but the idea for the ERCI does have some merit.
Helmut noted that the vision in Europe is the same. They are very interested in collaborating.

E. Aktan noted that there will be a second workshop in November in Tokyo. We should have a written draft of the report by then. In addition to the input that we have received here we look forward to more of it, over the next month, to month and a half. All input is welcome, especially input regarding intellectual challenges of designing and developing field laboratories and taking advantage of these effectively. All input will be incorporated and acknowledged in the report.

Dan Frangopol adjourned the meeting at 4:55 pm. He once again thanks A. Kiremidjian and Fu-Kuo Chang.

October 3, 2003

Recorder: Dr. Harry “Tripp” Shenton

Workshop Co-Chairs: Dr. Emin Aktan, Dr. Dan Frangopol and Dr. Hamid Ghasemi
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Appendix B

Slide Presentations from the Workshop
Held September 14, 2003
Palo Alto, California
Slides from the presentation made by Dr. Steve Chase at the workshop held September 14, 2004, Palo Alto, CA.
Delivering Infrastructure for America’s Future

Vision: Leadership for 21st Century
Stakeholder Driven and Involved

- *The Federal Role in Highway Research and Technology*, TRB Special Report 261
- National Highway R&T Partnership
- NCHRP 20/07 Task 121
AASHTO Thrust Areas/Business needs for Bridge Engineering

- Enhanced Materials, Structural Systems and Technologies
- Efficient Maintenance, Rehabilitation and Construction
- Bridge Management
- Enhanced Specifications for Improved Structural Performance
- Computer-Aided design, Construction and Maintenance
- Leadership
FHWA’s Role

Research and Technology
- Long Term
- High Risk – High Payoff
- National Coordination
- Delivery
- Deployment
Bridges for the 21st Century

Vision: Get in front of the bridge deterioration curve and stay there
Why?

- 160,000 bridges currently deficient
- 1 billion users cross deficient bridges each day
- Currently replacing or rehabilitating 10,000+ bridges per year at an annual cost of over $7B
- Over 3,000 bridges become deficient each year
- Users demand increased mobility and less congestion
- Bridges vulnerable to attack
Elements Critical for Success

People

Information

Technology

Deployment
FHWA Focus Areas

- Bridge of the Future
- Stewardship & Management
- Ensuring Bridge Safety, Reliability & Security
People

- A revitalized and modern Demonstration Projects Program
- Centers of Excellence
  - Work with UTC Programs
- A comprehensive suite of NHI courses
- Significant partnerships with industry
- Effective use of computer based training
- Outreach to future engineers
Information

- National Bridge Inventory (NBI) & Element Level Data
  - Bridge Management Information Systems Laboratory
- Nondestructive Evaluation (NDE) Center
- Long-term Bridge Performance Program
  - An ambitious new program to collect research quality data
Information

- A new Long-term Bridge Performance Program
  - Representative sample (thousands of bridges)
  - Program of detailed inspection and evaluations
  - Long term (at least 20 years and preferably longer)
  - Subset (hundreds) of instrumented “smart” bridges for continuous monitoring of operational performance
  - Forensic autopsies of decommissioned bridges

- Resultant database is essential to make informed decisions
Technology

- The Bridge of the Future
  - Material degradation no longer controls service life
  - A fraction of current construction time
  - A fraction of current LCC
  - Adaptable for new demands
  - Immune to attack, floods, earthquakes, overloads
  - A total systems approach
  - Vertical and lateral clearance problems eliminated
Technology

- Stewardship and Management
  - Better inspection, assessment and evaluation
  - Rapid strengthening, repair & restoration
  - Maintenance and preservation technologies
  - Research in deterioration science and control
  - The next generation of decision support and management systems
Ensuring Bridge Safety, Reliability and Security

- Earthquakes
- Scour
- Wind
- Collision
- Fire
- Floods
- Landslides
- Subsidence
- Overloads
- Attack

A consistent and comprehensive approach to designing for and managing risk
Technology

- Comprehensive decision support systems
  - Physically based deterioration models
  - Performance measures
  - Maintenance and preservation

- Emerging issues & technologies
  - Homeland security
  - Global warming
  - Assessment of tendons and cables
  - Ubiquitous computing
Deployment

- Highways for Life
- Redesign the IBRC Program emphasizing breakthrough innovation, new structural systems and streamlined construction that will become new standards
- Encourage greater risk taking
FHWA’s Vision for Bridge R&T

A strategic program to achieve specific goals

Information
People
Technology
Deployment
How does a FHWA/NSF Center contribute to this Vision?

- Complements Long-term Bridge Performance Program
- Complements Centers of Excellence Concept
- Provides a synergistic linkage between the missions and roles of FHWA and NSF
- Leverages resources to achieve shared goals
Thank you
Slides from the presentation made by Dr. Steve McCabe at the workshop held September 14, 2004, Palo Alto, CA.
A Research Initiative on Transportation Infrastructure, Bridges and Bridge Components

Workshop on NSF-FHWA joint Research
Palo Alto, CA
September 14, 2003
Steven L. McCabe Ph.D., P.E.

Program Director
Structural Systems and Hazard Mitigation
Division of Civil and Mechanical Systems
Directorate for Engineering
National Science Foundation
Arlington, VA 22230
These are my opinions....
Bridges represent a *huge* national issue

- Large Capital Investment when new
- Large Capital Investment for operation, maintenance and renovation
- Essential for Emergency Services
- Essential for our Modern Economy
- Social expectations
There is interest in bridges at NSF....

- Seismic performance of bridges
  - Systems
  - Superstructures
  - Components
  - Foundations
  - Retrofit and New Construction
There is interest in bridges at NSF….

- **Durability Issues**
  - New materials
  - New construction methods
  - Sensors
  - Health Monitoring in real time

- **Security**

- **Emergency response**
There is interest in bridges at NSF....

- These span the range of issues that CMS addresses in its programs
- Research is focused is –
  - Basic
  - Fundamental
  - Aimed at new knowledge, not applied
There is interest in bridges at NSF...

- Decisions in practice must be made looking at the entire problem - not just at bridges

- Comprehensive research looking at bridges as:
  - the keystone of a larger transportation system
  - dependent on the system and its reliability
  - Subjected to multi-hazards
NEES – a case in point

George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES)
NEES offers a unique opportunity

- Truly Collaborative research – a new model
- Significant new IT infrastructure
- Bridges will be a major topic of interest
- Many opportunities for health monitoring
National Science Foundation

Earthquake Engineering program

- Major shift in funding levels and approach being launched this year
- Initiating a three tiered plan for research
  - Grand Challenge Research
  - Small Group Research
  - Individual Investigator Research
NEESR: The Solicitation
Everyone has an Opportunity

NEES experimental, telepresence, data archival and collaborative capabilities have been designed to provide a pathway for earthquake engineering research and education partnerships that encourages broad participation in proposals from different segments of the earthquake engineering community (researchers, educators, practitioners, consultants, government agencies, national laboratories etc.).
Eligibility

- Only U.S. universities and colleges --- or US nonprofit organizations--- may submit proposals as the lead institution.

- Integrated partnerships are encouraged (i.e., multi-organizational arrangements including other universities and colleges, minority-serving institutions, women’s colleges, predominantly undergraduate institutions, national laboratories, private sector organizations, government agencies, and international collaborators).

- The number of participating organizations is not necessarily a measure of quality.
The Awards

- **GC Awards:**
  - Up to two per year; funding of up to $1,400,000 per year per award for up to five years.

- **SG Awards:**
  - Up to five per year; total funding of up to $600,000 per year per award for up to four years

- **II Awards:**
  - Up to ten per year; total funding of up to $150,000 per year per award for up to three years
Do the Math

- This works out to up to ~$ 9 million per year for the program.
- This represents additional new funding from NSF/ENG to support NEES in addition to a portion of the existing budget now spent on earthquake engineering research.
- Projects not involving NEES will still be reviewed and funded – but not under this solicitation.
Annual Deadline

Proposal Deadline Date(s) (due by 5 p.m. proposer's local time):

- **Letters of Intent due**
  
  December 8, 2003

- **Full proposals due**
  
  January 22, 2004
Payload Projects

The GC or SG project’s test set-up would provide the vehicle for testing the payload component.

- mechanical, control, sensing, structural or nonstructural component that may detect or support operation of the overall system,

GC and SG projects may include potential payload projects as part of the base proposal submission to this program solicitation;

NSF also may fund payload projects separately through the Small Grants Exploratory Research (SGER) program.
Key features of GC projects

- Strategic vision for a system-level problem requiring extensive use of NEES experimental resources;
- Seminal, rather than incremental, research that will advance the state-of-the-art;
- Strategic research plan to realize the vision;
- Research program encompassing a full spectrum of experimental and analytical investigations;
Key features of GC projects

- Opportunities provided under the GC to accommodate payload projects
- Project implementation plan, including a project schedule, project management plan, and organizational chart for all project phases
Key features of GC projects

- Education and outreach program
- Cross disciplinary and multi-institutional project team with broad geographic participation and including active participants from research institutions with NEES equipment awards, research institutions without NEES equipment awards and from primarily undergraduate institutions;
Key features of GC projects

- Project team and leadership diverse in gender, race, and ethnicity;
- Aggressive and innovative dissemination and transfer of findings to the entire earthquake engineering community
- Signed intellectual property agreement within six months of award
- *External* advisory board.
Data

All experimental and analytical data required to be submitted to the NEES data repository

- including full documentation of the associated metadata and the complete E-Notebook,
- in accordance with the data, metadata, and E-Notebook established policies set by NEES Consortium, Inc.
International Collaboration

- Strongly Encouraged -
  - if it makes sense

- Separate funding streams for US and non-US participants on a common project
  - NSF cannot fund foreign institutions or colleagues
Examples of NEES Research Possibilities…

- Performance-based earthquake engineering models and design criteria
- Multi-span structures: effects of spatial variation of ground motion on extended lifeline structures
- Nonstructural component response
- Large-scale/full-scale subassemblage testing
- Linear and nonlinear response mechanisms and models
- Soil-foundation-structure interaction and design
- Improved prediction of soil liquefaction, subsidence, lateral spreading, slope stability, and site amplification
- Feasibility and constructability studies for new systems
- Post-earthquake safety, repair, and loss estimation
- Coastal structures: tsunami-wave/structure interactions
Establishing the NEES/Earthquake Engineering Research Agenda

Developing a Long-Term Research Agenda for the Network for Earthquake Engineering Simulation
- Richard Little, PI, National Academy of Sciences, rlittle@nas.edu
- http://www4.nationalacademies.org

The Earthquake Research Plan: Research Needs and Opportunities for Earthquake Engineering
- Susan K. Tubbesing, PI, Earthquake Engineering Research Institute, skt@eeri.org
- http://www.eeri.org
NEESR Research Initiative

Available now on NSF website

http://www.nsf.gov/

Go to ENG and look for NEESR
Other NSF possibilities:

- Sensor Initiative each year
- ITR Solicitation

These are large and successful programs

- Not focused on any particular problem or area
NSF and FHWA Partnership for a Research Initiative on Transportation Infrastructure, Bridges and Bridge Components
What other possibilities exist?

- Developing research partnerships is one of the primary goals of NSF.
- What about a research funding partnership?
- What about a focused initiative looking at bridges, components and interrelated transportation system elements.
NSF and FHWA Partnership for a Research Initiative on Transportation Infrastructure, Bridges and Bridge Components

CMS is open to concept of a joint solicitation for research projects looking at bridge and system

- Durability
- Seismic Performance
- Security
- Sensors and Health Monitoring
- Reliability
- Decision making
NSF and FHWA Partnership for a Research Initiative on Transportation Infrastructure, Bridges and Bridge Components

- Multi-year program
- At least $3 million per year to make this work
- Jointly funded
- Bring in interested DOT’s as pooled fund participants
- Use a “NEES-like” approach
NSF and FHWA Partnership for a Research Initiative on Transportation Infrastructure, Bridges and Bridge Components

Could be very effective and “span” the range of issues

- Basic Research – NSF
- Longer term research aimed at specific issues – FHWA
- Shorter term research aimed at immediate issues – DOT pooled fund
International Partnerships for Research

- There is interest and activity already in place.
- Working on MOU between NSF and colleagues in
  - Japan - PWRI – to link NEES and E-Defense and other facilities
  - Europe
- Health Monitoring Community already has connections at the investigator level
**Knowledge Creation**

- *Style* of ENG-Supported Research Is Fundamental, Generic and Investigator Driven.
- A Variety of Research Modes Are Supported (and Kept in Careful Balance).
- Aim Is to Keep Disciplinary Research Strong and Encourage Flexibility to Work Across Disciplines and at Their Interfaces.
- Highest Priority: Preserve the Flexibility to Support the Most Creative Unsolicited Ideas and the Most Capable Researchers, As Selected Through Merit Review.
NSF and FHWA Partnership for a Research Initiative on Transportation Infrastructure, Bridges and Bridge Components

- We have parts of the initiative in place now at FHWA, NSF and the various DOT’s in the US
- Similar resources are in place in Japan and the EU
- Common problem -- individually we do not have sufficient funds to address these problems
- A coordinated push might help us all to get improved bridge and transportation system performance the attention it deserves
National Science Foundation

Where Discoveries Begin
Slides from the presentation made by the organizing committee at the workshop held September 14, 2004, Palo Alto, CA.
AGENDA

1. Overview of FHWA’s Infrastructure R&D Programs, and, the Long-Term Bridge Performance Research Program. Potential Contributions Anticipated From an NSF-FHWA Joint RCI. Dr. Steven Chase, Technical Director for Bridges, Office of Infrastructure R&D, FHWA

2. NSF’s Vision and Research Initiatives Related to CIS. Potential Contributions Anticipated from an NSF-FHWA Joint RCI. Dr. Steven McCabe, Program Director, Structural Systems and Engineering, NSF


4. Discussion and Future Steps
NSF-FHWA Engineering RCI

- NSF and FHWA are interested in establishing an RCI: “Advancing States-of-the-Art and Practice of Engineering and Management of the Highway Transportation Infrastructure”
- An exemplary academe-government-industry partnership
- Problem-focused, integrative and coordinated research taking advantage of field laboratories
- Field Labs will be distributed throughout the country, including some international sites
- Labs and researchers will remain connected in real-time, sharing networking, archival and library support and the benefits of an international Nexus
NSF-FHWA Engineering RCI: Organization and Administrative Structure-Draft

Oversight and Advisory Committee

Director and Executive Committee

Research Coordination Committee

Systems Integration, Data/Information Network Administration, and, Communications Center, Archives and Legacy Library

Web Edu

Field Laboratory 1

Field Laboratory 2

Field Laboratory 3

Field Laboratory N

NSF, FHWA

AASHTO, TRB, NCHRP, US Govt. Labs

International NEXUS

US Government Agencies Responsible for Safety, Security, Preservation and Sustainability of Critical Infrastructures

Professional Societies: ASCE, SPIE, IABSE, IABMAS, ITS-America, ACI, etc. and the entire International Infrastructure Research Community

Research Project 1

Research Project 2

Research Project 3

Research Project N

Education and Training Exe Com

Exe Com
NSF-FHWA Engineering RCI:

• A significant contributor to FHWA’s Long-Term Bridge Performance Research Program:
  – Data on representative sample (thousands of bridges)
  – Program of detailed inspection and evaluations
  – Long term (at least 20 years)
  – Subset (hundreds) of instrumented “smart” bridges for continuous monitoring of operational performance
  – Forensic autopsies of decommissioned bridges

• Contribute to FHWA’s research programs on pavements, traffic operations and security, help to integrate research on engineering and management of the entire system

• Integrate and synergize many fundamental elements of the current NSF, FHWA, NCHRP, other US government-funded and International research related to the highway transportation infrastructure
Field Laboratories - Test Beds:

• The field laboratory may be at the design, construction, operation, rehabilitation, retrofit or decommissioned stage

• Field labs should include all of the interacting human, natural and engineered elements (including traffic, drivers, organizational elements, security and enforcement, financing, politics, history)

• Field labs including intersections of various infrastructures (physical and organizational intersections between highways and railways, waterways, airports, and, water, power, fuel, communication systems) are especially desirable
Field Laboratories:

- Field laboratories are proposed, developed and maintained by academe-government (and industry, as applicable) partnerships. A long-term (e.g. 5-20 year) protocol and in-kind support by owner-agency

- Field labs may include major long-span bridge(s), tunnel(s), sample populations of operating bridges, decommissioned bridges, a regional network of highways, bridge(s) and traffic, various types of pavement and geo-technical structures, a major transportation hub serving a metropolitan area, etc.

- Field labs will serve to develop a new discipline focused on the engineering and management of hyper-systems, and evaluating and demonstrating innovative paradigms such as health monitoring, intelligent systems and integrated asset management with their associated technologies
HIGH-TECH FUTURE BEGINS TO TAKE SHAPE WITH TAMPA EXPRESSWAY

AN INNOVATIVE REVERSIBLE-lane elevated toll road is beginning to take shape in Hillsborough County, Fla. The three-lane, precast concrete elevated portion is being built on piers within the median of the Lee Roy Selmon Crosstown Expressway. When completed in 2005, it will provide added capacity to the direction most traveled by morning and evening commuter traffic and double as a research project for intelligent highway systems.

“Most [expressway] traffic is commuter traffic,” says Patrick McCue, executive director of the Tampa-Hillsborough County Expressway Authority. “So there is a need for more capacity at certain times of the day.” The $350-million project will help alleviate congestion for 75,000 daily commuters on the nine-mile stretch between downtown Tampa and Interstate 75 near Brandon, Fla.

PCL Civil Constructors Inc., a division of Edmonton-based PCL Enterprises, has a $145-million contract to construct most of the elevated six-mile portion leading to downtown as well as a section passing over I-75. Orlando-based Hubbard Construction will construct the at-grade three-mile portion and several feeder roads. David Dempsey, vice president of Hubbard Construction’s Tampa division, says its work is 15% complete, including 85,000 ft of barrier wall.

“This will be the most technologically sound stretch in the world,” McCue says, noting that up to $20 million is spent for information technology. Hollow cores of the precast segments allow for placement of sensors for intelligent highway systems.

“The importance of having such automation lies in driver safety and the increased [road] capacity—finding the right mix between what can be put in the roadway and what can be put in the vehicle,” he says. McCue says other cities are evaluating the project.

“This is the answer for the future of urban transportation,” says Linda Figg, president of Tallahassee-based Figg Engineering Group, the designer. No rights-of-way had to be obtained and existing traffic is not interrupted, she adds. The piers use just 6 ft of the expressway’s 40-ft median, “so there’s room to expand the expressway in the future.”

The viaduct’s precast segments weigh 90 tons each. Segments will be precast at the Port of Tampa and delivered to the site. PCL now is drilling shafts to 70-ft depths and has poured some of the supporting piers.
Possible Field Labs: Hoover Dam Bridge
Possible Field Labs: NY City East River Bridges
Profile of RC T-beam Bridges in PA

1,651 Single Span T-beam Bridges in PA

- Total Number in USA > 32,000
- Total Number in PA > 2600
- Type Specific Design
  - Built Between ~1930 & 1950
  - Span ~20 ft - 40 ft
  - Width ~ 20 ft - 40 ft
  - Skew ~ 0 - 45 deg
  - Slab Thickness ~ 8-8.5 in
  - Beam Spacing ~ 5 ft on center
  - Beam Depth ~ 19 in - 40 in

Bridge ID: 46-0029-0300-2175
Length = 34 ft
Year Built = 1954
Skew = 45 deg

Condition Rating
Deck | SuperStr | SubStr
--- | --- | ---
6 | 6 | 5

Standard Design Dwgs.
Statistical Sampling

Location & Density

Entire T-Beam Bridge Population

<table>
<thead>
<tr>
<th>Span</th>
<th>16 ft to 32 ft</th>
<th>33 ft to 40 ft</th>
<th>41 ft to 55 ft</th>
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<thead>
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<th>1939 to 1948</th>
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Statistical Representative 60 T-Beam Bridges

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Possible Field Laboratory
Network of Colorado Bridges

Akgul and Frangopol 2003
Developed Software Architecture

Structure Types Database

Member Types Database

Integrated Reliability Analysis System (IRAS (NREL SYS))

Integrated Simulation System (ISIS (MONTE CARLO))

Live Load Models (LMs)

Resistance Deterioration Model Database (RMDB)

Akgul and Frangopol 2003
Possible Field Laboratory

Honshu-Shikoku Bridges

Imai and Frangopol 2003
Systems and Systems Engineering:

• **System** is a set of elements integrated for a purpose. Each element may serve a different function, but their integration serves a common purpose that requires functioning of all elements. **Hyper-Systems** integrate systems of human, natural and engineering elements.

• **Systems Engineering** includes observing, conceptualizing, physical and analytical modeling, measuring-and-perturbing, identifying, simulating, monitoring, controlling, interpreting data, lifecycle cost optimization and decision-making for the purpose of enhancing the performance, preservation and protection of a system.
FUNDAMENTAL ISSUES:

Modeling, analysis and management of hyper-systems by Integrating all of their human, natural and engineered elements

Identification and simulation of interconnections and interactions between human, natural and engineered elements of hyper-systems

Observing and measuring all of the elements of a hyper-system in real-time by advanced sensing, networking, data management systems

Visualization and interpretation of measurement data, integration of images and data for information and synthesis for knowledge

Intelligent Materials, Components and Systems, Knowledge-Intensive Multiple Agent System Applications

Less Known and Unknown Mechanisms of Uncertainty Affecting Performance and Life-Cycles of Infrastructure Hyper-Systems
CONSTRUCTED SYSTEMS: ISSUES

• Reliable and Practical Objective Data Complementary to Visual – Heuristic Evaluation of Structural Conditions, Global Health and Sufficiency
• Structural Damage Detection: Definition, Indices, Algorithms
• Definition and Evaluation of Structural System Capacity, Reliability and Redundancy – Revisiting Fracture Critical Elements/Systems
• Fatigue Detection, Loading-Life Estimation and Extension
• Design and Construction for Improving Serviceability and Durability,
• Evaluation of Multi-Hazards Vulnerability, Effective Mitigation Measures
• Effective Maintenance, Rehabilitation, Retrofit and Hardening
• Health and Performance Monitoring (including NDE) for transition to Performance Based Engineering
• Advanced Materials and Systems: HPC, HPS, synthetic and bio-based composites, Innovative Systems
OPERATIONS: ISSUES

• Safety of Operations and Impact of Bridges on Operational Safety
• Congestion Management, Impact of Bridges on System Efficiency
• Traffic Network Connectivity
• ITS technologies for enhancing safety, efficiency, security and emergency management
• Detection, Surveillance and Communication Technologies not yet in ITS Realm for Homeland Security and Emergency Management
Traffic Operations Research

• **Traffic Surveillance:**
  Loop detectors, Video, Probe vehicles, MEMS, UAVs

• **Data Analysis and Performance Evaluation:**
  Congestion detection, PeMS, Bottleneck analysis, patterns

• **Traffic Flow Modeling:**
  Microscopic models (car-following theory), Macroscopic models (fluid flow, kinematic wave theory)

• **Operational Strategies:**
  Ramp metering, signal coordination, traveler information systems, dynamic lane assignment (HOV lanes, merging), speed control

• **Field Operational Testing Lab:**
  California PATH Test beds (at UC Berkeley and UC Irvine)
TMS (Transportation Management System)

TMS are the business processes and associated tools, field elements and communication systems that help maximize the productivity of the transportation system.
INTEGRATED ASSET MANAGEMENT

• Sustainability, Environmental Considerations, Planning and Policy
• Valuation and Impact of Financing and Other Mechanisms
• Performance Measures, Constraints and Objective Functions
• Data Needs, Analysis Engines and Objective Functions for Optimum Performance and Life-Cycle Management of Hyper-Systems
• Impacts of social, political, financial, organizational constraints
• Integration of Bridge and Pavement Management Systems; Operations and Maintenance Management
• Incorporation of data from health and performance monitoring systems into bridge, pavement and operations management
ASSET MANAGEMENT (AS)

- AS? Scientific methods for deciding when, where, and how to spend maintenance, preservation, and improvement resources in the most cost-effective way

- According to FHWA, AS is “A systematic approach to the allocation of resources for the management, operation, and preservation of transportation infrastructure”

- AS involves measuring and monitoring performance of individual and networks of infrastructures with or without maintenance

- Research needed to develop multi-objective optimization model for asset management of civil infrastructures, including, among others, condition, reliability, security, sustainability, and cost
LIMITATIONS OF CURRENT BMS

- Subjective assessment (visual inspection) and empirical transition models are used (condition state)
- Bridge system performance is not generally addressed (element level, single failure mode)
- Bridge safety and security are not directly incorporated

THEORY vs. APPLICATIONS of LCC

- Life-cycle cost and performance criteria for deteriorating civil infrastructures have now attained some degree of maturity
- Applications of these criteria are still in infancy

RECENT ADVANCES

- Data on structural performance, environmental conditions and cost
- Health monitoring
- Structural system reliability and optimization

Frangopol 2003
RESEARCH NEEDS

- Analyze the interactions between condition, rating, safety, security, and cost of transportation infrastructures
- Develop methods able to capture uncertainties propagating over time
- Develop a framework applicable not only to project level but also to network level
- Apply the developed framework to real transportation infrastructures
- Identify optimal maintenance strategies based on life-cycle performance, security and cost
- Study the consequences of infrastructures failure (economic, political, social, cultural, environmental, …)
- Develop methodologies to formulate decision problems and evaluate infrastructure management strategies with the consideration of interdependency of different infrastructures

Frangopol 2003
Paradigm Shift and New Challenges

- 9/11 terrorist attack poses new challenges
  - Is it technically and economically possible to design structures to resist such an attack?

KINETIC ENERGY AT IMPACT

- Mitchell Bomber (B-25)
  - ~ 320 km/hr
  - Plane = 11,000 kg

- BOEING 707
  - ~ 290 km/hr
  - Plane = 119,000 kg

- BOEING 767
  - ~ 944 km/hr
  - Plane = 125,000 kg

COMBUSTION ENERGY OF FUEL

- Mitchell Bomber (B-25)
- BOEING 707
- BOEING 767

As considered in design
Not considered in design

September 11
September 11

Courtesy of NAE
Blackout Impacts were widespread...

- **Transportation Impacts included:**
  - **Airports** – many airports suffered extended flight delays and temporary shutdowns (NY, Cleveland, Toronto)
  - **Subways** – it took 2-1/2 hours to evacuate passengers from stalled subway trains in NYC
  - **Commuter trains** stopped between NY & NJ. Ferries used as an alternate.
  - **Amtrak** stopped all trains leaving the NY area, and in Michigan
  - **Roadways** – traffic signals out, motorists advised to stay off roads.

Photos: CNN.com
Damage of Traffic Network System (1)

Elysian Park (M7.1) (before retrofit)

The result of one simulation.
Damage of Traffic Network System (2)

The result of one simulation.

Elysian Park (M7.1) (after retrofit)
## Benefit-Cost Analysis

<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>Annual Probability of Failure</th>
<th>Annual Expected Loss</th>
<th>Effect of Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Retrofit</td>
<td>After Retrofit</td>
<td>Before Retrofit</td>
</tr>
<tr>
<td><strong>Model 1</strong></td>
<td>0.111%</td>
<td>0.036%</td>
<td>$414</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td>0.221%</td>
<td>0.037%</td>
<td>$10,083</td>
</tr>
<tr>
<td><strong>Model 3 (Gavin Canyon)</strong></td>
<td>0.765%</td>
<td>0.227%</td>
<td>$5,201</td>
</tr>
<tr>
<td><strong>Model 4 (Santa Clara)</strong></td>
<td>0.082%</td>
<td>0.025%</td>
<td>$8,944</td>
</tr>
<tr>
<td><strong>Model 5 (SR14/I5 Interchange)</strong></td>
<td>0.858%</td>
<td>0.318%</td>
<td>$100,938</td>
</tr>
<tr>
<td><strong>General</strong></td>
<td>0.407%</td>
<td>0.129%</td>
<td>$20,368</td>
</tr>
<tr>
<td><strong>Total Annual Expected Loss</strong></td>
<td></td>
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<td><strong>61 milions</strong></td>
</tr>
</tbody>
</table>

(Approximate 3000 Bridges)
## Loss Due to Drivers’ Delay Comparison; With vs. Without Retrofit

<table>
<thead>
<tr>
<th>Scenario earthquake</th>
<th>Loss due to drivers’ delay (without retrofit)</th>
<th>Loss due to drivers’ delay (with retrofit)</th>
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<tbody>
<tr>
<td>Newport-Inglewood(S) M7.0</td>
<td>$4,742,160</td>
<td>$274,270</td>
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<tr>
<td>Newport-Inglewood(N) M7.0</td>
<td>$10,601,060</td>
<td>$976,530</td>
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<tr>
<td>Elysian Park M7.1</td>
<td>$15,729,700</td>
<td>$1,022,715</td>
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<tr>
<td>Malibu Coast M7.3</td>
<td>$56,938,400</td>
<td>$6,246,940</td>
</tr>
</tbody>
</table>

*$50/hour*
SAR simulation
Output from X-patch

X-patch Specifications
* Freq. = X band
* Polarization = VV
* Resolution = 1m
* Flight path = parallel to bridge

Before

After

No damage

Fallen span
Comments ?
Questions ?
Feedback ?
Appendix C

Minutes of the Workshop Held November 12, 2003
Tokyo, Japan
NSF-FHWA- Univ. of Tokyo Workshop

on

Advancing the States-of-the-Art and Practice of the Engineering and Management of the Highway Infrastructure

Workshop venue: Lecture Hall, No.1 Engineering Building, Hongoh Campus
Date: Nov. 12, 2003  10 am- 5:45pm

Objectives of the Workshop

1. To discuss a proposed US NSF-FHWA Joint Engineering Research Consortium Initiative (RCI), that is based on taking advantage of field test-sites.
2. To discuss the intellectual challenges related to creating and taking advantage of a number of networked field test-sites to serve as laboratories for fundamental problem-focused research.
3. To discuss how the US Initiative may be extended to include test sites in other countries.

Protocols and other issues related to networking the field laboratories, data archives and the researchers from different countries into an International Nexus.

Program(tentative)

10:00-10:15   Opening remarks
10:15-10:30   Goals of the Workshop (Aktan, Frangopol, Ghasemi, McCabe)
10:30-11:00   US-FHWA (Ghasemi)
11:00-11:30   US-NSF (McCabe)
11:30-12:00   US Exe Committee Presentation (Emin Aktan, Dan Frangopol, Tripp Shenton, Masanobu Shinozuka)
12:00-13:00   Lunch
13:00-13:35   Dr. Hyung Bae KIM and Dr. Heungbae GIL (the Korea Highway Corporation (KHC), Construction and Operation of KHC test road, and current status of Korea highway facilities and related KHC's activities;

Prof. Hyun-Moo Koh (Seoul National University)
Structural Health Monitoring of Bridges and National Research Programs in Korea

13:35-15:55    Dr. Aftab A. Mufti (President ISIS Canada, University of Manitoba Canada)
Canadian Experience in Structural Health Monitoring of Innovative Structures.
13:55-14:30
Prof. Ko, J-M (Hong Kong Polytech Univ.)
Current status of Structural Health Monitoring of Long Span Bridges in Hong Kong

Dr. WONG, Kai-Yuen   Highways Department   Hong Kong
Monitoring of large bridges in Hong Kong

14:30- 15:20
Dr. H. Wenzel(VCE, Austria)
European Position on sustainable Infrastructures

Mr. Feltrin(EMPA, ETH)
Current and Future Activities at EMPA

Dr. Eugen Bruhwiler  EPFL  Germany

15:20-15:35 coffee break

15:35-16:05
Prof. OU Jinping (Harubin Inst. Of Technology)
Some recent advances of intelligent health monitoring systems for large bridges in mainland of China

Prof.LI (Harubin Inst. Of Technology)
Design Approaches and Implementations of Wind-induced Vibration - MR Damping Control for Cables of Cable-stayed Bridges-

16:05   8 min. each
Candidates;
Japan Highway Corporation
Tokyo Metropolitan Expressway Public Corporation
Honshu-Shikoku Bridge Authority
   Mr.Kawaguchi Koji  Maintenance Management of Long Span Bridges -Monitoring System-
Hanshin Expressway Corporation

Prof. Ohshima (Kitami Inst. Of Technology)
Prof. Miyamoto (Yamaguchi University)
Prof. Wu (Ibaraki University)
   Structural health monitoring/management of FRP strengthened structures
Prof Dogaki(Kansai University)

Dr. Sasaki (Tokyo Inst. Of Technology)
Dr. Kaito (BMC)  Maintenance and monitoring of railway systems
Dr. Sumitoro (Keisoku Research)
   Some Field Application Examples of Actual-stress Based SHM in Japan
Dr. Shiba(Shimizu Corp.)
Dr. Kaneji (Kajima Corp.)
(Prof. Fujino)

17:50  Closing remarks

18:00  Party (we will joint the party of the Infrastructure Symposium at Sanjyo Hall, Univ. of Tokyo.
       All participants are invited to the party)

Note: Sandwich and drinks will be served for the lunch)
NSF-FHWA-Univ. of Tokyo Workshop

on

Advancing the States-of-the-Art and Practice of the Engineering and Management of the Highway Infrastructure

Minutes of the Workshop

Workshop Venue: Lecture Hall, No.1 Engineering Building, Hongoh Campus
Date: November 12, 2003 10:00 AM-5:45 PM

Attendees: See the attached list.

The workshop was called to order by Prof. Yozo Fujino at 10:03 AM. Fujino welcomed the participants. He stated that the objective of the workshop is to discuss the proposed US NSF-FHWA joint engineering research consortium initiative that is based on the taking advantage of field test sites. Creating and taking advantage of a number of networked field test-sites to serve as laboratories for fundamental problem focused research would be discussed. Fujino also added that the initiative may be extended to include test sites in other countries and protocols and other issues related to networking the field laboratories, data archives and bringing researchers from different countries will be discussed in this workshop.

Fujino requested the workshop participants to introduce themselves.

Fujino requested Professor Dan Frangopol to give an overview of the workshop. Frangopol presented the objectives of the workshop. A previous presentation was held at Palo Alto, California on September 14, 2003. This workshop will be the continuation of the efforts based on the feedback provided at Palo Alto meeting and this workshop aims to bring researchers from other countries.

Frangopol introduced the first speaker, Dr. Hamid Ghasemi.

Presentation by Dr. Hamid Ghasemi, Program Manager, Federal Highway Administration.

The first part of Ghasemi’s presentation is on the Proposed NSF/FHWA Research Initiative. The second part is an overview of FHWA’s Infrastructure R&D programs and the long-term bridge performance research program. Ghasemi stated that Dr. Balaguru would present NSF’s vision and research initiatives related to civil infrastructure. Ghasemi added that Drs. Aktan, Duwadi, Frangopol and Shinozuka would present the draft structure and principles of the proposed NSF-FHWA initiative.
Ghasemi started with the NSF-FHWA developing a partnership. He outlined that NSF funds basic, fundamental research aimed at developing new technologies and FHWA is more interested in applied research, training and to push technologies and standards. Ghasemi noted that there is great benefit from a synergistic link between the mission and the roles of NSF and FHWA. Ghasemi presented that the partners for the initiative are Drs. Steven McCabe and Perumalsamy Balaguru from NSF Division of Civil and Mechanical Systems, and Drs. Steven Chase, Hamid Ghasemi and Ms Sheila Duwadi from FHWA Office of Infrastructure R&D.

Ghasemi stated that the academic coordinators for the Initiative are Drs. Aktan, Frangopol, Shinozouka, Shenton, Madanat. Ghasemi added that a wide participation from different interested researchers is expected and the Initiative is will support a collaborative effort.

Ghasemi then outlined the objectives of the Initiative as a) to create an international nexus for infrastructure innovation, b) develop problem-focused, integrated, and coordinated research centered around field laboratories, c) connect labs and researchers in real-time, sharing data, and information, d) to guide and complement FHWA’s long-term bridge performance program, and e) to provide a synergistic link between the mission and roles of NSF and FHWA.

Ghasemi stressed that there is an urgent need to develop a rational, integrated and optimal approach to the management of our infrastructure. As a result, Ghasemi noted the first goal of the Initiative is to coordinate and conduct meaningful research, with resources provided by the NSF and FHWA that is problem focused, and that can be used for improving infrastructure efficiency, protection and preservation. The second goal of the Initiative is to develop a paradigm for integrating all of the factors that enhance safety, security and reliability of infrastructure systems with participation by Government, Academe, and Industry. To enable that, Ghasemi noted that they would have to create funding mechanisms similar NEES program. Another goal of the Initiative is to establish field laboratories throughout the country (or world) to conduct problem-focused, integrated, and coordinated research. These field laboratories would be used to evaluate and demonstrate innovative paradigms for a proactive approach to the management of the infrastructure systems Ghasemi exemplified the new paradigms as integrated risk and asset management, health monitoring and ITS.

After introducing the new Initiative, Ghasemi presented an overview of the strategic direction of the FHWA R&D program. He stated that the federal role in highway research and technology is given in TRB Special Report 261, the National Highway R&T Partnership, and the HNHRP 20/07 Task 121. Ghasemi overviewed the AASHTO thrust areas/business needs for bridge engineering which is in Partnership Report. These needs are a) enhanced materials, structural systems and technologies, b) effective maintenance, rehabilitation and construction, c) bridge management, d) enhanced specifications for improved structural performance, e) computer aided design, construction and maintenance. In that context, FHWA’s role is conduct long term, high risk-high payoff
research while providing a national coordination. FHWA also promotes the delivery of technology and especially promotes the deployment of new technology.

Ghasemi stated that the vision of FHWA for the Bridges for the 21st Century was getting in front of the bridge deterioration curve and staying there. The reasoning behind this vision is that there are 600,000 bridges in the US and 160,000 bridges are currently deficient. One billion users cross deficient bridges every day. Ghasemi pointed out that the currently replacing or rehabilitating 10,000 bridges per year costs more than $7B while more than 3,000 bridges become deficient each year. In the mean time, there is a demand for increased mobility and less congestion. Also, bridges are vulnerable to natural and man-made hazards.

Ghasemi identified people, information, technology and deployment as the four critical elements for success of the FHWA focus areas a) bridge of the future, b) stewardship and management, and c) ensuring bridge safety, reliability and security.

The first critical element is people; FHWA would like to establish centers of excellence that work with UTC programs. FHWA is also interested in revitalized and modern demonstration research projects. Ghasemi also stated that FHWA would like to see a comprehensive suite of NHI courses that are updated and revised. Partnership with industry such as certification for engineers, inspectors is significant. FHWA also stresses that effective use of computer based training is needed. Finally, FHWA sees that it is very important to outreach future engineers.

The second critical element for success is information; FHWA has been updating and using the National Bridge Inventory (NBI) which consists of element level data. However, there is a need to improve the current NBI. The future Bridge Management System (BMS) will have to include the efforts of Nondestructive Evaluation (NDE) Center, have to integrate probability and multi-objective optimization towards having quantitative data.

The long term bridge performance program vision of FHWA is to collect data from representative sample (thousands of bridges), conduct detailed inspections of these bridges. A subset of these bridges will be instrumented as “smart” bridges and be monitored continuously for operational performance. Another area FHWA would like to focus is to conduct forensic autopsies of decommissioned bridges. These efforts will lead to a database which is essential to make informed decision.

With regard to bridge of the future, FHWA envisions a bridge that has 100 year life with zero maintenance. This bridge will be constructed in a fraction of the current construction time, in a fraction of the current LLC and it will be adaptable for new load demands, will be immune to attack, floods, earthquakes, overloads without any vertical and lateral clearance problems. A total systems approach is needed to fulfill this vision.

On the stewardship and management, Ghasemi outlined that FHWA identified the following needs: rapid strengthening, repair and restoration, new maintenance and
preservation technologies, more research in deterioration science and control. There is a need for better information for making better decision and better information can be obtained using new non-destructive evaluation methods.

FHWA would like to ensure bridge safety, reliability and security for earthquakes, floods and scour, extreme wind events, landslides, collision and attack. Comprehensive decision support systems with deterioration models, performance models that make sense are needed for better decisions about maintenance and preservation. Some of the emerging technologies that need exploration are homeland security, global warming, assessment of tendons and cables, and finally nano-technology. FHWA would like to redesign the IBRC program emphasizing breakthrough innovation, new structural systems and streamlined construction that will become new standards.

Ghasemi concluded his presentation by stating that the new NSF/FHWA Initiative will complement the long-term bridge performance vision of FHWA. It also complements the centers of excellence and provides a synergistic link between the mission and roles of NSF and FHWA.

Next speaker was Dr. Perumalsamy Balaguru, Program Manager, National Science Foundation.

Balaguru stated that Dr. Steven McCabe was originally scheduled to make the presentation. Balaguru started with a general overview of the NSF organizational structure and budget distribution. The total annual budget of NSF for all different directorates is about $5B. Out of the entire budget, approximately 10% is allocated to Directorate for Engineering. Approximately, 10% of the engineering budget goes to Civil and Mechanical systems.

Balaguru indicated that bridges require large capital investments and NSF has funded research on bridges, especially on seismic performance of bridges including system, superstructures and elements. Some of the relevant issues to bridges are performance, durability, security, emergency response. NSF is interested in supporting fundamental research projects on these areas. The research projects should not be applied since NSF funds basic, fundamental research to develop new knowledge.

Balaguru overviewed the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). It is a new program. It is a distributed virtual laboratory. The data collected through NEES will be shared. Significance of NEES is the use of IT between collaborators. This will enable researchers to run experiments remotely. Bridges will be an area of research within NEES program.

Balaguru presented the funding levels through the NEES program; Grand Challenge (GC), Small Group (SG) and Individual Investigator (II). The GC projects are to have experimental and analytical components, to have a diverse project group. Cross-disciplinary and if it makes sense, multi-organizational collaborations are encouraged.
Also, external advisory board is needed for GC projects. All the data collected by NEES support will be stored in a data repository.

Balaguru also overviewed some of the other NSF initiatives. Sensors and IT programs are also large and successful programs. These programs do not focus on any particular problem.

Balaguru then overviewed the NSF-FHWA Initiative. He stated that initially it is envisioned to jointly invest at least $3M per year to start. It will have to bring in other interested parties. The new initiative will complement NSF’s basic research and FHWA’s long-term bridge vision by having an organization with a structure similar to NEES.

Balaguru finalized his presentation by re-iterating that NSF funds basic research and new ideas. Examples are nano-technologies and for bridges, applications like material that will resist 500 Fahrenheit temperature.

Next speaker is Prof. Emin Aktan from Drexel Infrastructure Institute, Drexel University.

Aktan stated that the new NSF-FHWA Initiative will be composed of a diverse group of researchers. Aktan indicated that NSF-FHWA requested a group to serve as coordinators for the Initiative. The Initiative will be an exemplary academe, government and industry partnership since academics need to answer real life questions. The Initiative will be more problem focused.

Aktan presented a tentative organizational structure for the proposed Initiative. A similar organizational structure to NEES can be envisioned. NSF and FHWA will provide the direction for the Initiative. The Initiative will contribute to the FHWA long-term bridge program and complement FHWA’s efforts.

Aktan also stated that the Initiative will also be an integrative and synergistic effort for many of the research ideas funded by NSF and FHWA related to transportation infrastructure.

Aktan indicated that the field laboratories will be a cornerstone of the Initiative. For the field laboratories, partnership with agencies that own infrastructure is important. The field laboratories will be interconnected and networked. The field laboratories may be long bridge(s), tunnel(s), a sample population of operating bridges, a regional network of highways, bridges and traffic etc.

Aktan then briefly overviewed possible examples: New York City East River Bridges, Hoover Dam Bridge, Population of Bridges in Pennsylvania, Network of Bridges in Colorado, elevated highway in Florida and Honshu_Shikoku Bridges in Japan.

The next speaker is Prof. Dan Frangopol from University of Colorado, Boulder.
Frangopol continued on the research thrusts of the Initiative. The main research thrusts of the Initiative would be a) Systems and Systems engineering, b) Constructed systems, c) Operation, d) Integrated Asset Management and e) Security. Frangopol stated that there are fundamental issues with current systems engineering approaches such as modeling, analysis and management of the systems by integrating all of their human, natural and engineered elements. Systems approach is needed to identify and to simulate the interconnections and interactions between human, natural and engineered elements of systems.

With regard to constructed systems, reliable, practical and objective data which will complement to visual, heuristic evaluation of structural condition is a fundamental issue.

As for the operations, Frangopol briefly discussed the safety operations and impact of bridges on operational safety, traffic network connectivity, ITS technologies for enhancing safety, efficiency, security and emergency management. Frangopol briefly talked about transportation management system (TMS). Frangopol mentioned that Dr. Madanat was initially scheduled to present issues related to traffic operations and how they relate to the Initiative but he could not come to the workshop since he had other engagements.

Frangopol overviewed the fundamental issues related to integrated asset management. Limitations of the current BMS do not address the needs for system performance, bridge safety and security. Although research studies on life cycle cost and performance criteria have some degree of maturity now, there is still a gap between the theory and applications of LLC.

Frangopol also discussed research needs on integrated asset management. There are research needs for analyzing the interactions between condition, rating, safety, security and costs of transportation infrastructures, for developing methods to capture uncertainties and for developing project level as well as network level frameworks. These frameworks have to be applied to real transportation infrastructures. Frangopol concluded his presentation stating that there is an urgent need to study the consequences of infrastructure failures which have economic, political, social, cultural and environmental impacts.

The next speaker was Ms. Sheila Duwadi, PE, Team Leader, Bridge Safety, Reliability and Security, FHWA.

Duwadi talked about the Security program at FHWA and how it relates to the proposed NSF-FHWA Initiative. Duwadi showed the map of the highway infrastructure in the US. The highway system consists of around 47,000 miles of Interstate highways. There are 590,000 bridges and 200 tunnels in the highway infrastructure.

Duwadi stated that 60% of all traffic and 80% of all truck traffic are on the national highway system. There is also 1.5 billion tons of hazardous material that move through the system each year. Therefore there are issues related to accidents, security and safety
of the highway system. In addition, there are navigable waterways. As for the transportation mode comparison, one barge on a navigable waterway is equivalent to 15 railcars or to 60 trucks.

FHWA identified research needs for transportation safety and security. Duwadi concluded her presentation with the FHWA R&D roadmap for these areas. The strategic focus areas are system analysis and design, improved materials, prevention and detection, post event assessment, repair and restoration and finally evaluation and training.

Next presentation by Prof. Masanobu Shinozuka, University of California, Irvine.

Shinozuka discussed a paradigm shift and new challenges after the September 11 terrorist attacks. Shinozuka stated that he has been conducting research on lifeline systems for many years. Life line systems have many components which are not protected and therefore they are vulnerable. He also discussed recent blackouts and the impacts on transportation including airports, subways, commuter trains, roadways etc.

Shinozuka presented a damage simulation on traffic network system near Los Angeles, California before and after retrofit. An important aspect is to conduct benefit-cost analysis. Shinozuka presented the economic impact of retrofit for the simulations and indicated the major savings in the case of retrofit.

Shinozuka also discussed some of the new technologies such as satellite imagery. An example application was in Taiwan for quick evaluation of urban damage. Other technologies are SAR imagery which has relatively less resolution but it is useful at all weather conditions.

Shinozuka indicated the importance of international collaboration for prevention, protection and post-event response. He indicated that there is a need for real time monitoring technologies, especially real time post-event response monitoring. The new Initiative addresses these issues also.

Ghasemi concluded the presentations on the new Initiative. Ghasemi indicated the importance and significance of international collaboration.

Then Ghasemi opened the floor for questions and discussion.

A. Mufti indicated that there is a need for developing guidelines and recommendations for the new technologies and this would provide better acceptance from organizations such as AASHTO.

V. Karbhari pointed out that it is important to document the real costs of a bridge or a lifeline to understand the impact of using new technologies. He indicated that NEES was formed out of years of collaboration of earthquake centers of excellence, US-Japan collaboration, conferences. It was not the case for health monitoring of transportation systems. Karbhari’s observation was that the efforts were mainly driven by the funding
supplied for the research projects. He asked about the funding mechanisms and criteria and added that academic community can resolve what could be done with the data.

Ghasemi indicated that the Initiative should start somewhere. The initiative is open to everyone and will be coordinated. Currently, the budget is the main issue to have a concrete program.

B. Yanev asked what the first steps of the Initiative would be.

Ghasemi indicated that the initial goal is to come up with some seed money. The research will be coordinated accordingly. Identifying and using the field laboratories is also very important. At this point, we need some seed money and a basic research demonstration before we go to congress to request more funding for the Initiative. Therefore, basic research demonstration is very important.

L.Olson asked whether the funding would be part of the new authorization.

Ghasemi noted not yet. There is proposal at this time. The first step is to have NSF support and then go to congress.

L.Comfort as a public policy analyst stated that the complexity of infrastructure ownership is a challenge. State, federal, county and private ownerships exist. For example, in there are about 700 bridges in Pittsburgh owned by different entities. She asked if a comprehensive program not only for monitoring structures but also for policy and strategy for managing the entire bridges is considered.

S. Duwadi answered that there is currently a federally mandated national bridge inspection program. For the new Initiative what can and cannot be done is to be discussed.

Ghasemi pointed out that the budget is the number issue and with enough funds a lot can be done for coordination, education and training of engineers, inspectors. However, we need a much larger participation than only the FHWA R&D office.

W. Saltzberg indicated that bridge engineers have to deal with many issues. An example is flood. Recently security has become a major issue. For any research concept, we have to have demo-projects for bridge engineers/owners. In Canada, only after successful demonstration projects, state bridge engineers agree to implement research. There should be money to fund real life research and unless we conduct field research, there is long ways to go.

Ghasemi indicated the importance of education and training. One of the objectives of the Initiative is to educate bridge engineers/owners on the use of the new technologies.

Mufti commented that liability is a major issue for real life research. He also added that reliability research is a need and asked the group members how this is considered.
Shinozouka replied that international collaboration will be important. He also added that International Association of Safety and Reliability conference can be a medium. If this organization can help, he would be happy to promote this meeting. Shinozouka stated that there should be a sharp focus on bridges, transportation system, lifeline systems.

F. Ansari commented that the Initiative should offer something different. We already have a lot of research in areas such as asset management. There should be new ideas and we will have to consider where we would like to be in five years.

C. Sikorsky asked what the contributions of different states would be and how.

Ghasemi replied that they would like to have researchers from states, they would like to have them in committees.

L. Olson mentioned the US-Japan workshops and asked what can be done for this Initiative similar to those workshops.

Ghasemi noted that collaborations take time. We would be connecting through e-mails, would have to start collaborating. Other US groups will be included in this collaboration.

Olson asked about the time of the initial funding.

Ghasemi replied that the first funding might come next year or so. Then, we hope to raise more money in the next 3-4 years.

Ansari commented that convincing DOTs would be worthwhile. Its return will help in the in the short-run, however, we need strategies for this.

Ghasemi noted that as FHWA, they have been working DOTs in the areas of education, coordination. Coordinating efforts with DOTs will be important. This Initiative is a start; there is long ways to go.

Yanev indicated that bridge owners’ needs are immediate. He gave the NYC blackout example. It is very important to deliver to the bridge owners when promised.

Fujino adjourned the meeting at 12:09 PM for lunch and he requested everyone to be at the workshop at 1:00 pm for the afternoon session.

The afternoon session was held between 1:00 pm 5:55 pm with several presentations of researchers from Korea, Canada, Hong Kong, China, Europe, China, Japan. (Please see the program of the presenters.)

At 5:55 pm, Prof. Shinozuka summarized the workshop.
Shinozouka mentioned that he was impressed with the advanced technologies and applications presented by the workshop presenters. He also commended the enthusiasm of the participants.

Shinozouka pointed out that it is easier to define monitoring. He commented that it is more difficult but more critical to define the structural health. He added that this NSF-FHWA Initiative would seek this answer.

Shinozouka stated that information technology and other new technologies are available, however deployment for structural safety and security is needed. He indicated that there are many bridges which are new and supposed to be healthy. However, measurement for design and performance is needed.

With regard to maintenance, some of the maintenance objectives are idealistic. What a system can endure is to be investigated. Uncertainty issues should be addressed.

Shinozouka pointed out that there might be some concerns and some could think nothing new about the Initiative. He gave the example of SCADA. He indicated that lifeline system companies such as water companies benefit greatly from real time monitoring for decision making. However, the current SCADA systems are sparse and mainly for preservation. The next generation monitoring systems will include components such as security monitoring for human loss reduction. In the case of an event, we will have to respond immediately. The new Initiative addresses these needs. Shinozouka indicated that with support from NSF and FHWA, the Initiative would be successful.

Balaguru commented that the organizers should think where we would like to go from here. Inclusion of facilities world-wide would be good, however, it is also very important to include other sciences such as social sciences, education and technology transfer in the new Initiative.

Dr. Fujino adjourned the meeting at 6:05 pm, thanked the participants and asked everyone to join the party at Sanjyo Hall.

November 12, 2003
Recorder: Dr. F. Necati Catbas
Workshop Chair: Dr. Yozo Fujino.
List of Participants
November 12, 2003 Workshop – Tokyo, Japan

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Appendix D

Slide Presentations from the Workshop
Held November 12, 2003
Tokyo, Japan
Slides from the presentation made by Dr. Hamid Ghasemi at the workshop held November 12, 2003, Tokyo, Japan
A Proposed NSF/FHWA Research Initiative: Advancing the States-of-the-Art and Practice of the Engineering and Management of Infrastructure Systems

Hamid Ghasemi, Ph.D.
Program Manager
Health Monitoring
Federal Highway Administration
McLean, Virginia
USA

November 12, 2003
Tokyo University
Japan
AGENDA

1. Goals of the Proposed Initiative, (Dr. Hamid Ghassemi)

2. Overview of FHWA’s Infrastructure R&D Programs and the Long-Term Bridge Performance Research Program.  
   
   Dr. Hamid Ghasemi, Office of Infrastructure R&D,  FHWA

3. NSF’s Vision and Research Initiatives Related to CIS.  
   
   Dr. Steven McCabe, Program Director, Structural Systems and Engineering, NSF

   
   Drs. Aktan, Frangopol, Ghasemi, Shenton and Shinozuka

5. Discussion and Future Steps
PARTNERS

- NSF (Division of Civil & Mechanical Systems)
  - Dr. Steven McCabe
  - Dr. Perumalsamy Balaguru

- FHWA (Office of Infrastructure R&D)
  - Dr. Steven Chase
  - Dr. Hamid Ghasemi
  - Ms. Sheila Duwadi
PARTNERS Continued…..

- ACADEMIA
  - Dr. Emin Aktan (Drexel Infrastructure Institute)
  - Dr. Dan Frangopol (U. of Colorado at Boulder)
  - Dr. Masanobu Shinozuka (U. of California, Irvine)
  - Dr. Tripp Shenton (U. of Delaware)
  - Dr. Samer Madanat (U. of California Berkeley)
OBJECTIVE

• To create an international nexus for infrastructure innovation
• To complement the new, long-term bridge performance program
• Resultant database is essential to make informed decisions
• Collaborate effectively with knowledgeable parties in developing a rational and economical, integrated approach to management of our infrastructure systems
SHORT-TERM GOAL

- NSF and FHWA will provide resources for conducting meaningful research that is problem focused, as opposed to technological gadgetry, that can be used for improving infrastructure efficiency, protection and preservation
MID-TERM GOAL

• With participation by government, academe, and industry, develop a paradigm for integrating all of the factors that provide benefits to current infrastructure systems
LONG-TERM GOAL

- Create funding mechanisms (similar to NEES program)
- Establishing bridge laboratories to conduct problem-focused, integrated, and coordinated research
- These bridge laboratories will be distributed throughout the country (or world) for evaluating and demonstrating innovative techniques for a proactive management of the infrastructure system. Examples of such techniques are:
  - Integrated risk and asset management
  - Health Monitoring
  - System Engineering Tools (i.e., ITS)
Slides from the presentation made by the organizing committee at the workshop held November 12, 2003, Tokyo, Japan
A Proposed NSF/FHWA Research Initiative: Advancing the States-of-the-Art and Practice of the Engineering and Management of Infrastructure Systems

Emin Aktan, Ph.D.
Dan Frangopol, Ph.D.
Sheila Duwadi, P.E.
Masanobu Shinozuka, Ph.D.
Tripp Shenton, Ph.D.
Elements of the FHWA’s Long-Term Bridge Performance Research Program:

- Data on representative sample (thousands of bridges)
- Program of detailed inspection and evaluations
- Long term (at least 20 years)
- Subset (hundreds) of instrumented “smart” bridges for continuous monitoring of operational performance
- Forensic autopsies of decommissioned bridges

- The ERCI would be a significant contributor to the Long-Term Bridge Performance Program, providing support and expertise; a role in all aspects of the program
NSF-FHWA Engineering Research Consortium Initiative

- Complement FHWA’s research programs on pavements, traffic operations and security, help to integrate research on engineering and management of the entire system

- Integrate and synergize many fundamental elements of the current NSF, FHWA, NCHRP, other US government-funded and International research related to the highway transportation infrastructure
Field Laboratories - Test Beds: 
*The cornerstone of the ECRI*
Field Laboratories - Test Beds:  
The cornerstone of the ECRI

- Field labs may include, for example
  - major long-span bridge(s)
  - typical or innovative grade crossing bridge(s)
  - tunnel(s)
  - a sample population of operating bridges
  - decommissioned bridges
  - a regional network of highways, bridges and traffic
  - various types of pavement and geo-technical structures
  - a major transportation hub serving a metropolitan area, etc.

- Field laboratories may be at the design, construction, operation, rehabilitation, retrofit or decommission phase of the life-cycle

- Field labs may be developed from existing or new structures/systems
Field Laboratories -Test Beds:
The cornerstone of the ECRI

- Field laboratories are proposed, developed and maintained by academe-government (and industry, as applicable) partnerships. A long-term protocol (e.g. 5-20 year) and in-kind support by owner-agency

- Field labs should include all of the interacting human, natural and engineered elements

- Field labs including intersections of various infrastructures (physical and organizational intersections between highways and railways, waterways, airports, and, water, power, fuel, communication systems) are especially desirable

- Field labs will serve to develop a new discipline focused on the engineering and management of hyper-systems, and evaluating and demonstrating innovative paradigms such as
  - health monitoring,
  - intelligent systems and
  - integrated asset management with their associated technologies
Possible Field Lab: NY City East River Bridges
Possible Field Lab: Hoover Dam Bridge
Possible Field Lab: Population of RC Bridges in PA

1,651 Single Span T-beam Bridges in PA

• Total Number in USA > 32,000
• Total Number in PA > 2600
• Type Specific Design
  ➔ Built Between ~1930 & 1950
  ➔ Span ~ 20 ft - 40 ft
  ➔ Width ~ 20 ft - 40 ft
  ➔ Skew ~ 0 - 45 deg
  ➔ Slab Thickness ~ 8 - 8.5 in
  ➔ Beam Spacing ~ 5 ft on center
  ➔ Beam Depth ~ 19 in - 40 in
Possible Field Lab: Network of Bridges in Colorado

Akgul and Frangopol 2003
HIGH-TECH FUTURE BEGINS TO TAKE SHAPE WITH TAMPA EXPRESSWAY

An innovative reversible-lane elevated toll road is beginning to take shape in Hillsborough County, Fla. The three-lane, precast concrete elevated portion is being built on piers within the median of the Lee Roy Selmon Crosstown Expressway. When completed in 2005, it will provide added capacity to the direction most traveled by morning and evening commuter traffic and double as a research project for intelligent highway systems.

“Most [expressway] traffic is commuter traffic,” says Patrick McCue, executive director of the Tampa-Hillsborough County Expressway Authority. “So there is a need for more capacity at certain times of the day.” The $350-million project will help alleviate congestion for 75,000 daily commuters on the nine-mile stretch between downtown Tampa and Interstate 75 near Brandon, Fla.

PCL Civil Constructors Inc., a division of Edmonton-based PCL Enterprises, has a $145-million contract to construct most of the elevated six-mile portion leading to downtown as well as a section passing over I-75. Orlando-based Hubbard Construction will construct the at-grade three-mile portion and several feeder roads. David Dempsey, vice president of Hubbard Construction’s Tampa division, says its work is 15% complete, including 35,000 ft of barrier wall.

“This will be the most technologically sound stretch in the world,” McCue says, noting that up to $20 million is spent for information technology. Hollow cores of the precast segments allow for placement of sensors for intelligent highway systems.

“The importance of having such automation lies in driver safety and the increased [road] capacity—finding the right mix between what can be put in the roadway and what can be put in the vehicle,” he says. McCue says other cities are evaluating the project.

“This is the answer for the future of urban transportation,” says Linda Figg, president of Tallahassee-based Figg Engineering Group, the designer. No rights-of-way had to be obtained and existing traffic is not interrupted, she adds. The piers use just 6 ft of the expressway’s 40-ft median, “so there’s room to expand the expressway in the future.”

The viaduct’s precast segments weigh 90 tons each. Segments will be precast at the Port of Tampa and delivered to the site. PCL is drilling shafts to 70-ft depths and has poured some of the supporting piers.
Possible Field Lab: Honshu-Shikoku Bridges

- RELSYS(CALREL) INTERFACE FEAP
  - CALL LIMITFG
  - LIMITFG INPUT DATA EXECUTE FEAP
  - CALL GRADFG
  - GRADFG K(GLOBAL)
  - COMEpute \( \frac{\partial g}{\partial v} \)
  - \( K(\text{LOCAL}) \)
  - COMEpute \( \beta_{\text{NEW}} \)
  - \( \beta_{\text{NEW}} = \beta_{\text{OLD}} \)
  - END

Imai and Frangopol 2003
Field Lab Network

• Field laboratories to be networked, providing real-time access to test sites across the country.....a “collaboratory”
• Secure, central repository for archiving data and information
• Standards established for documenting and archiving data
• Perhaps modeled after the George E. Brown Network for Earthquake Engineering Simulation (NEES)
Research Thrusts for the ECRI
Research Thrusts for the ECRI

- Systems and Systems Engineering
- Constructed Systems
- Operation
- Integrated Asset Management
- Security
System is a set of elements integrated for a purpose. Each element may serve a different function, but their integration serves a common purpose that requires functioning of all elements.

Hyper-Systems integrate systems of human, natural and engineering elements.

Systems Engineering includes observing, conceptualizing, physical and analytical modeling, measuring-and-perturbing, identifying, simulating, monitoring, controlling, interpreting data, lifecycle cost optimization and decision-making for the purpose of enhancing the performance, preservation and protection of a system.
Systems and Systems Engineering: Fundamental Issues

- Modeling, analysis and management of hyper-systems by integrating all of their human, natural and engineered elements
- Identification and simulation of interconnections and interactions between human, natural and engineered elements of hyper-systems
- Observing and measuring all of the elements of a hyper-system in real-time by advanced sensing, networking, data management systems
- Visualization and interpretation of measurement data, integration of images and data for information and synthesis for knowledge
- Intelligent Materials, Components and Systems, Knowledge-Intensive Multiple Agent System Applications
- Less Known and Unknown Mechanisms of Uncertainty Affecting Performance and Life-Cycles of Infrastructure Hyper-Systems
Constructed Systems: Fundamental Issues

• Reliable, practical, and objective condition assessment data - complementary to visual, heuristic evaluation of structural condition, global health and sufficiency

• Structural damage detection: definition, indices, robust algorithms, cost-effective

• Definition and evaluation of structural system capacity, reliability and redundancy

• Fatigue detection, loading-life estimation and extension, fracture critical elements/systems, repair and retrofit of damaged details

• Design and construction for improving serviceability and durability
Constructing Systems: Fundamental Issues

- Evaluation of multi-hazards vulnerability, effective mitigation measures
- Effective maintenance, rehabilitation, retrofit and hardening
- Health and performance monitoring (including NDE) for transition to Performance Based Engineering
- Advanced materials and systems:
  - HPC
  - HPS
  - Synthetic and bio-based composites
  - Innovative systems
Operations: Fundamental Issues

- Safety of operations and impact of bridges on operational safety
- Congestion management, impact of bridges on system efficiency
- Traffic network connectivity
- ITS technologies for enhancing safety, efficiency, security and emergency management
- Detection, surveillance and communication technologies not yet in ITS realm for homeland security and emergency management
Traffic Operations: Issues

- Traffic Surveillance:
  Loop detectors, Video, Probe vehicles, MEMS, UAVs

- Data Analysis and Performance Evaluation:
  Congestion detection, PeMS, Bottleneck analysis, patterns

- Traffic Flow Modeling:
  Microscopic models (car-following theory), Macroscopic models (fluid flow, kinematic wave theory)

- Operational Strategies:
  Ramp metering, signal coordination, traveler information systems, dynamic lane assignment (HOV lanes, merging), speed control

- Field Operational Testing Lab:
  California PATH Test beds (at UC Berkeley and UC Irvine)
TMS (Transportation Management System)

TMS are the business processes and associated tools, field elements and communication systems that help maximize the productivity of the transportation system.
Integrated Asset Management (AS): Fundamental Issues

• AS: Scientific methods for deciding when, where, and how to spend maintenance, preservation, and improvement resources in the most cost-effective way

• According to FHWA, AS is “A systematic approach to the allocation of resources for the management, operation, and preservation of transportation infrastructure”

• AS involves measuring and monitoring performance of individual and networks of infrastructures with or without maintenance

• Research needed to develop multi-objective optimization model for asset management of civil infrastructures, including, among others, condition, reliability, security, sustainability, and cost
Integrated Asset Management: Fundamental Issues

LIMITATIONS OF CURRENT BMS

• Bridge system performance is not generally addressed (element level, single failure mode)
• Bridge safety and security are not directly incorporated

THEORY vs. APPLICATIONS of LCC

• Life-cycle cost and performance criteria for deteriorating civil infrastructures have now attained some degree of maturity
• Applications of these criteria are still in infancy
Integrated Asset Management:
Fundamental Issues

RECENT ADVANCES

- Data on structural performance, environmental conditions and cost
  Health monitoring
- Structural system reliability and optimization
Integrated Asset Management: Research Needs

- Analyze the interactions between condition, rating, safety, security, and cost of transportation infrastructures
- Develop methods able to capture uncertainties propagating over time
- Develop a framework applicable not only to project level but also to network level
- Apply the developed framework to real transportation infrastructures
Integrated Asset Management:
Research Needs

- Identify optimal maintenance strategies based on life-cycle performance, security and cost
- Study the consequences of infrastructures failure (economic, political, social, cultural, environmental, …)
- Develop methodologies to formulate decision problems and evaluate infrastructure management strategies with the consideration of interdependency of different infrastructures
SECURITY

Fundamental Issues
Highway Infrastructure

- 74,942 km (46,567 miles) of Interstate Highways
- 183,438 km (113,983 miles) of other NHS roads
- 6,069,591 km (3,771,462 miles) of other roads
- 590,000 bridges
- 200 tunnels
Traffic

• National Highway System
  • 60% of all traffic
  • 80% of all truck traffic

• Navigable Waterways
  • One barge – equivalent of 15 rail cars or 60 commercial trucks
  • One 15-barge tow – equivalent of 21 – 4 unit trains or 870 commercial trucks

• Hazmat transport
  • 1.5 billion tons of hazardous materials move through the system each year

TRANSPORTATION MODE COMPARISON

<table>
<thead>
<tr>
<th>1 Barge</th>
<th>15 Railcars</th>
<th>60 Trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,500 Tons</td>
<td>100 Tons</td>
<td>25 Tons</td>
</tr>
<tr>
<td>52,500 Bushels</td>
<td>3,500 Bushels</td>
<td>875 Bushels</td>
</tr>
<tr>
<td>453,600 Gallons</td>
<td>30,240 Gallons</td>
<td>7,560 Gallons</td>
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Courtesy of MARAD, USDOT
## RD&D Roadmap

### Strategic Focus Areas

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<tr>
<th>FY 03</th>
<th>FY 04</th>
<th>FY 05</th>
<th>FY 06</th>
<th>FY 07</th>
<th>FY 08</th>
<th>FY 09</th>
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<td><strong>System Analysis &amp; Design</strong></td>
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<td><strong>Improved Materials</strong></td>
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Security: Fundamental Issues

- Design, maintenance and operation for security
- Innovative protective measures
- Vulnerability assessment
- Multi-hazard mitigation
- ?
Paradigm Shift and New Challenges

• 9/11 terrorist attack poses new challenges
  – Is it technically and economically possible to design structures to resist such an attack?
Blackout Impacts were widespread...

- **Transportation Impacts included:**
  - **Airports** – many airports suffered extended flight delays and temporary shutdowns (NY, Cleveland, Toronto)
  - **Subways** – it took 2-1/2 hours to evacuate passengers from stalled subway trains in NYC
  - **Commuter trains** stopped between NY & NJ. Ferries used as an alternate.
  - **Amtrak** stopped all trains leaving the NY area, and in Michigan
  - **Roadways** – traffic signals out, motorists advised to stay off roads.

Photos: CNN.com
Damage of Traffic Network System (1)

- Elysian Park (M7.1) (before retrofit)

- The result of one simulation.
Damage of Traffic Network System (2)

Elysian Park (M7.1) (after retrofit)

The result of one simulation.
### Benefit-Cost Analysis

<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>Annual Probability of Failure</th>
<th>Annual Expected Loss</th>
<th>Effect of Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Retrofit</td>
<td>After Retrofit</td>
<td>Before Retrofit</td>
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<tr>
<td><strong>Model 1</strong></td>
<td>0.111% 0.036%</td>
<td>$414 $170</td>
<td>$244</td>
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<tr>
<td><strong>Model 2</strong></td>
<td>0.221% 0.037%</td>
<td>$10,083 $2,111</td>
<td>$7,972</td>
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<tr>
<td><strong>Model 3</strong> (Gavin Canyon)</td>
<td>0.765% 0.227%</td>
<td>$5,201 $1,928</td>
<td>$3,273</td>
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<td><strong>Model 4</strong> (Santa Clara)</td>
<td>0.082% 0.025%</td>
<td>$8,944 $3,365</td>
<td>$5,579</td>
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<tr>
<td><strong>Model 5</strong> (SR14/I5 Interchange)</td>
<td>0.858% 0.318%</td>
<td>$100,938 $46,744</td>
<td>$54,193</td>
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<td><strong>General</strong></td>
<td>0.407% 0.129%</td>
<td>$20,368 $8,035</td>
<td>$12,333</td>
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<tr>
<td><strong>Total Annual Expected Loss</strong> (Approximate 3000 Bridges)</td>
<td><strong>61 milions</strong></td>
<td><strong>24 milions</strong></td>
<td><strong>37 milions</strong></td>
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</tbody>
</table>
## Loss Due to Drivers’ Delay Comparison; With vs. Without Retrofit

<table>
<thead>
<tr>
<th>Scenario earthquake</th>
<th>Loss due to drivers’ delay (without retrofit)</th>
<th>Loss due to drivers’ delay (with retrofit)</th>
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<tr>
<td>Newport-Inglewood(S) M7.0</td>
<td>$4,742,160</td>
<td>$274,270</td>
</tr>
<tr>
<td>Newport-Inglewood(N) M7.0</td>
<td>$10,601,060</td>
<td>$976,530</td>
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<tr>
<td>Elysian Park M7.1</td>
<td>$15,729,700</td>
<td>$1,022,715</td>
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<tr>
<td>Malibu Coast M7.3</td>
<td>$56,938,400</td>
<td>$6,246,940</td>
</tr>
</tbody>
</table>

*$50/hour*
921 地震災後埔里地區衛星影像

Source Data: IKONOS PAN+XS

Acquisition Date/Time: 1999-10-21 01:56
SAR simulation
Output from X-patch

X-patch Specifications
* Freq. = X band
* Polarization = VV
* Resolution = 1m
* Flight path = parallel to bridge

Before

After

No damage

Fallen span
International Collaboration