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Our Roles…

Leaders for National Mobility.

Stewards for National Highway Programs.

Innovators for a Better Future

Our Values Statements. . .

The people who make up the FHWA family are dedicated to providing the leadership necessary to improve the Nation's transportation system today and in the future. We pursue excellence in all of our endeavors. Our commitment is reflected in our core values:

Public Service – We are committed to the pursuit of professional excellence motivated by serving the public interest and providing high quality products and timely services.

Integrity – Ethics, fairness and honesty define the way we do our work and conduct ourselves. We have the courage to both be innovative and make tough decisions.

Respect – We value individual diversity and the unique strengths, skills, expertise, and background of our employees. We treat others in a polite and courteous manner.

Family - We support, care about, listen to and respond to employees and their family needs.

Collaboration – We maximize our collective talents through teamwork and partnerships based on mutual trust, respect, support, cooperation and communication.

Personal Development – Through a wide variety of learning opportunities, we nurture the development and use of leadership, technical and professional skills in all of our employees.

The FHWA is organized around a headquarters office in Washington, DC; a Division Office in each State (including the District of Columbia, and Puerto Rico); a resource Center at four locations; and three Federal Lands Highway Division Offices. The Office of Research Development and Technology, located in McLean, VA conducts research in support of the FHWA mission using a variety of techniques and materials. The FHWA organization is portrayed in Figure I-1.

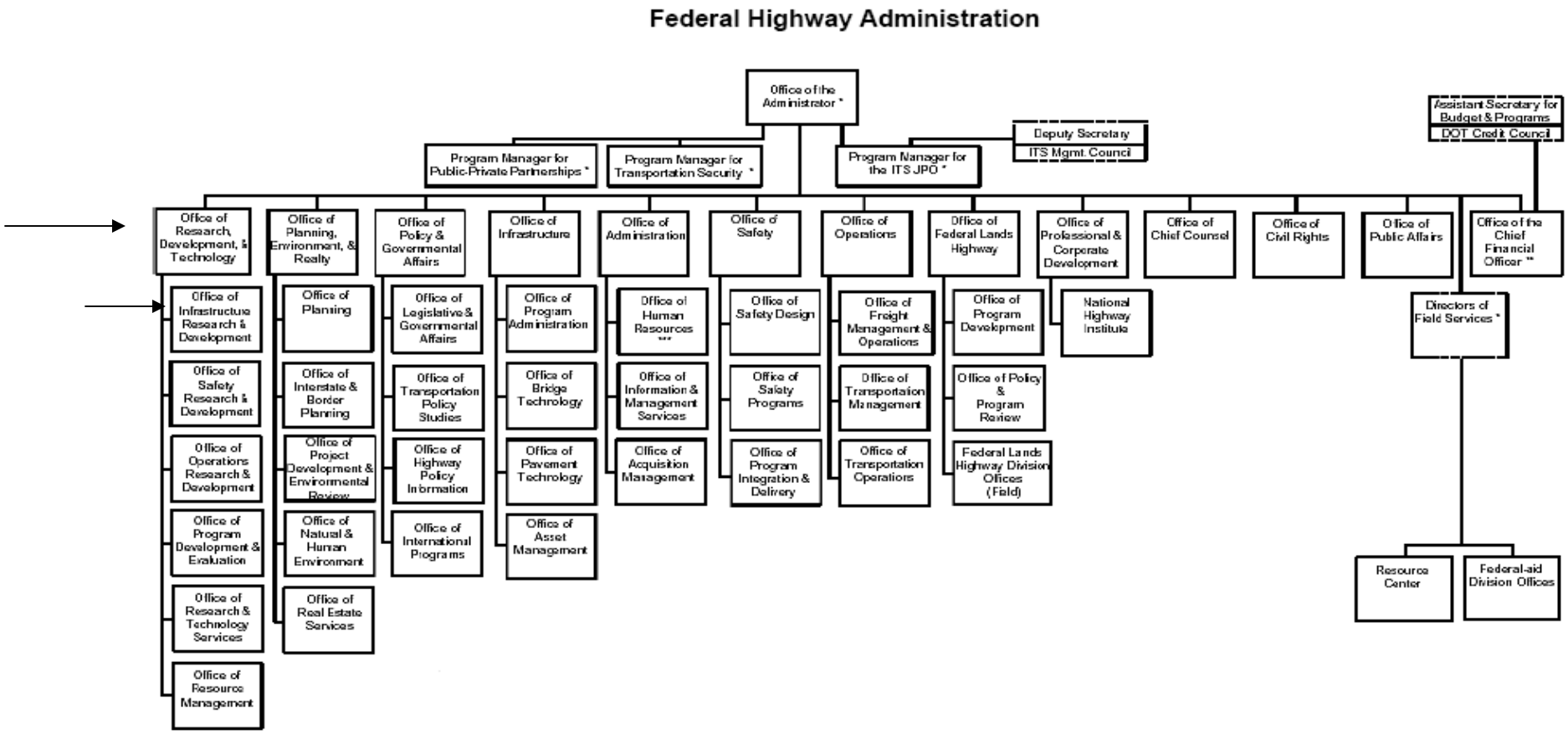

Figure I-1. Organization Chart of FHWA. Office of Research Development and Technology is represented by the far left column.

Turner Fairbank Highway Research Center

The Turner-Fairbank Highway Research Center (TFHRC) is a Federally owned and operated research facility in McLean, Virginia, with 24 indoor and outdoor laboratories and support facilities. It is the home of the FHWA's Office of Research, Development, and Technology (RD&T), which directly supports the vision, mission, and goals of the U.S. Department of Transportation (USDOT) and FHWA by addressing the significant transportation challenges that face our Nation today.

To support the FHWA role of "Innovators for a Better Future," TFHRC leadership is committed to:

- Invest in and conduct transportation research with and on behalf of partners and stakeholders.
- Create an environment for and deliver innovation in the transportation community through the development of tools, technology transfer, training, and technical assistance.
- Continually reevaluate and improve the effectiveness and efficiency of our key business process of technology and innovation deployment.

In light of these guiding principles, TFHRC provides FHWA, its customers and stakeholders, and the world highway community with advanced research and development related to new highway technologies. The focus at TFHRC is on solutions to complex technical problems by developing economical, environmentally sensitive designs; efficient, quality-controlled construction practices; durable materials; and products that result in a safer, more reliable highway transportation system.

Research conducted at TFHRC, as shown in Figure I-2, by the Offices of Safety Research and Development, Operations Research and Development, and Infrastructure Research and Development, spans myriad topics including: Human Centered Systems; Materials Technology, Operations & Intelligent Transportation Systems (ITS), Pavements, Safety, and Structures. The expertise of approximately 300 Federal and Contract scientists, engineers, and research staff, encompassing more than100 transportation-related disciplines, is focused on this work.

TFHRC coordinates and collaborates extensively with other FHWA and DOT offices, State and local government partners, academic organizations, companies in the industry, military research offices, and professional organizations to quickly and cost-effectively transform new technologies and concepts into better transportation systems, processes and services.

To help FHWA carry out a nationwide research and technology (R&T) program, the Office of Program Development and Evaluation develops and executes policy, budget, program management, and administrative mechanisms; the Office of Research and Technology Services develops and executes a comprehensive RD&T communications strategy and marketing plan that supports FHWA R&T programs and technology transfer and delivery; and the Office of Resource Management provides administrative services for RD&T.

The Office of Corporate Research and Technology (HRTC) support FHWA's commitment to implement the Corporate Master Plan for Research and Deployment of Technology and Innovation through the facilitation of various agency wide activities that are initiated by the FHWA R&T Leadership Team. Through these initiatives that are acted upon in conjunction with key stakeholders, HRTC strengthens FHWA's role as a national leader in highway research and technology.

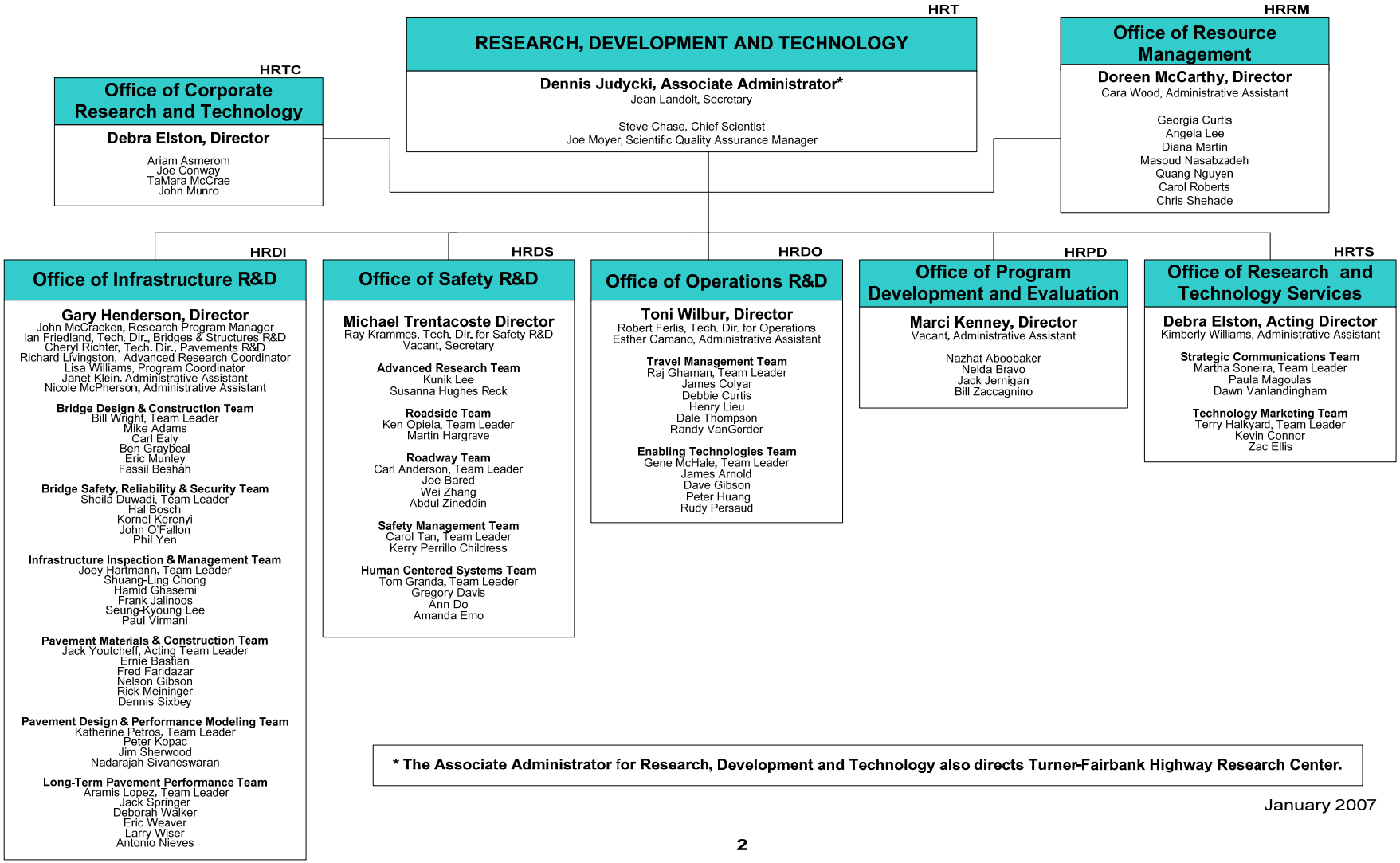

Figure I-2. Federal Highway Administration Turner-Fairbank Highway Research Center

The Office of Infrastructure R&D

The Office of Infrastructure R&D portrayed in Figure I-3 includes highway structures and pavements, and is made up of seven teams shown on the office organizational chart. The office originally had thirteen teams but several were combined to leave the seven that now operate. Teams HRDI-06, 07 and 10 make up the Office of Infrastructure Structures R&D; teams HRDI-11, 12 and 13 make up the Office of Infrastructure Pavements R&D. Team HRDI-05 is a cross cutting team that address advanced research concepts. HRDI-10 Infrastructure Inspection and Management is where the Nondestructive Evaluation Center resides.

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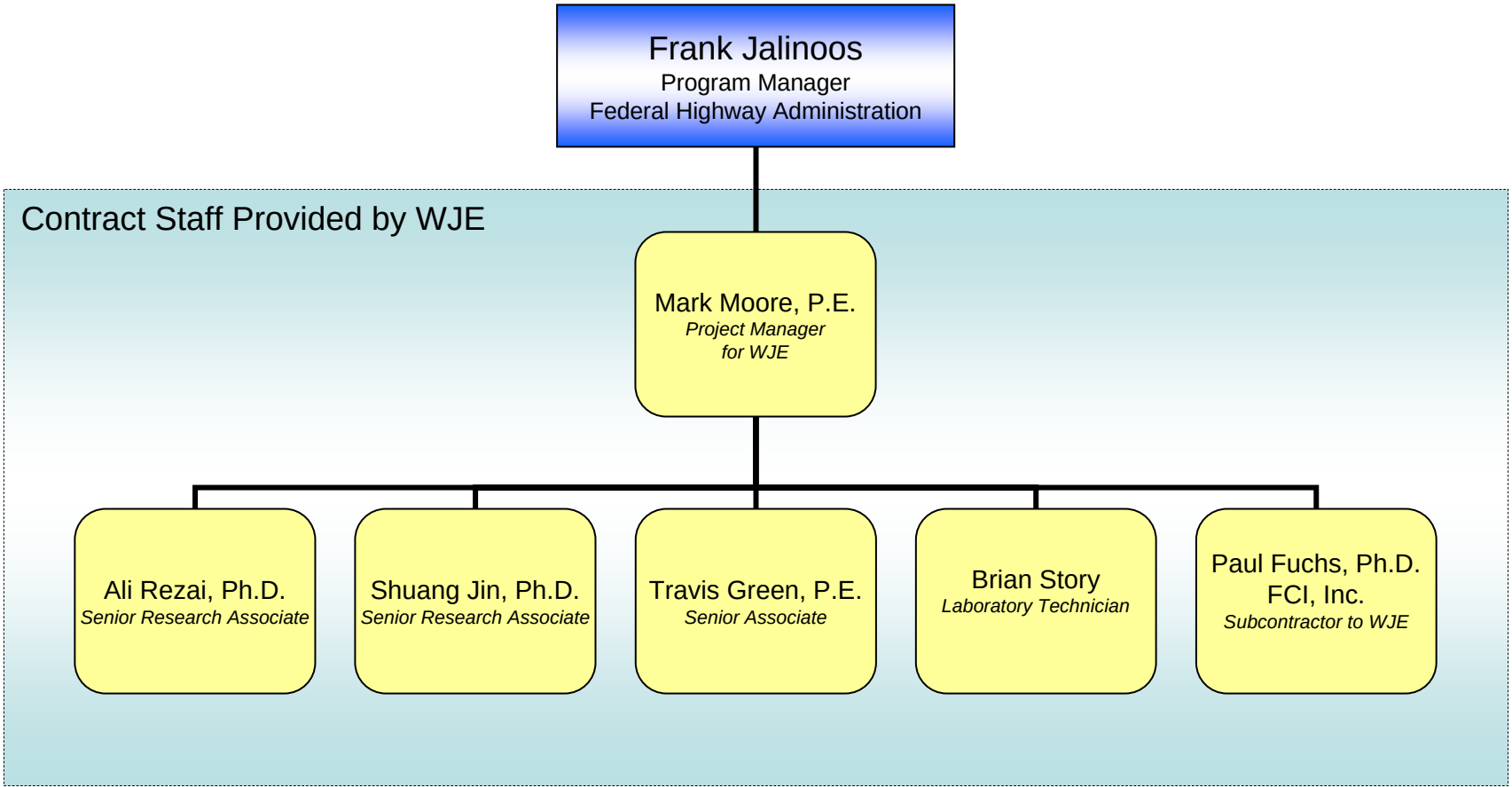
Figure I-3. FHWA Office of Infrastructure R&D

Non-Destructive Evaluation Center

The NDE Center operates under the direction of Frank Jalinoos, Office of Infrastructure as shown in Figure I-4. The Center is staffed and operated by the prime Laboratory Support Contractor, Wiss, Janney, Elstner Associates, Inc. (WJE). Mr. Mark Moore, P.E. is the Program Manager for the WJE Contract and serves as our point of contact. The WJE's research personnel under Mr. Moore consists of Dr. Ali Rezai and Dr. Shuang Jin, both senior research engineers; Mr. Brian Story, senior laboratory specialist; Mr. Travis Green, research engineer; and Dr. Paul Fuchs, research specialist. Mr. Green works off-site on a part-time basis. Dr. Fuchs is an employee of FCI Consulting who is a subcontractor to WJE.

FHWA NDE Center



Background

The FHWA's Nondestructive Evaluation Center is the keystone of the FHWA's research and testing efforts related to the application of nondestructive testing technologies for assessment of highway infrastructure. The mission of the NDE Center is:

…to conduct state-of-the-art research and testing of nondestructive testing systems and technologies to improve the nation's highway infrastructure

The NDE Center was established by the FHWA in 1996 in an effort to centralize and better coordinate research related to nondestructive testing. Prior to establishing the NDE Center, there was no centralized organization or program within the FHWA to respond to the needs of other FHWA organizations and/or individual state departments of transportation. Since the establishment of the NDE Center, the primary role of the Center has been to be a resource to FHWA and the States for information and expertise on nondestructive testing tools and technologies.

Prior to establishing the NDE Center, the FHWA was active in research related to some NDE technologies including ultrasonic's, ground penetrating radar, infrared thermography and radiography. While some of this research was conducted at the Turner-Fairbank Highway Research Center, the vast majority of the work was carried out off-site and facilitated through various research contracts issued and administered by the FHWA. Throughout the 1980s and 1990s the dramatic advances in the microprocessor led to the rapid development of NDE systems and tools with more capabilities and improved field portability. (Figure I-5). Because a vast majority of NDE tools and systems rely on the transmission of signals (or waves) through the structure and the assessment of those signals, computers play a vital role in virtually all NDE systems. Accordingly, as the speed and computational capacity of microprocessors increased 1000 fold in the 1980s and 1990s, the resulting capabilities of NDE tools and systems advanced significantly.

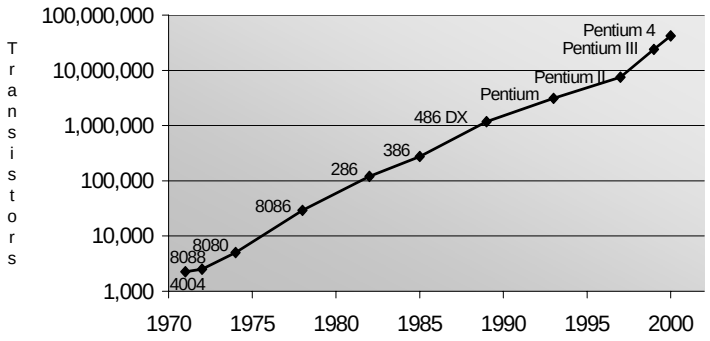


Fig. I-5 - Increase in number of transistors per microprocessor.

A direct result of these dramatic improvements in capabilities to capture, process, and analyze signals and waveforms, was an increased number of commercially available NDE tools available to bridge owners. These new tools represented a wide range of capabilities that bridge owners had a difficult time evaluating and making independent assessments.

Accordingly, one of the long standing objectives of the NDE Center is to conduct research and testing on commercially available NDE systems to independently assess the current capabilities, make recommendations to potential users of the advantages and disadvantages

of selected systems, and make recommendations to manufacturers and system developers for improvements and added capabilities.

Overview of Operations

The NDE Center is a unique laboratory that consists of two distinct components; the physical laboratory space at the Turner-Fairbank Highway Research Center and a series of in-service and decommissioned bridge structures where experimental work can be conducted under operational conditions. It is this unique combination of a physical laboratory and in-place bridge structures that allows the NDE Center to conduct research and testing under a variety of conditions. Please refer to the "Facilities and Equipment" Section for a more detailed description of the NDE Center.

Research and testing activities at the NDE Center are typically identified based on needs and interests expressed by the FHWA based organizations, state DOT's, industry and academia. After an area of need has been identified, a preliminary plan for the required research and testing is developed. These preliminary plans are frequently vetted both within the FHWA and the NDE community for comment.

Relationship with Other Nondestructive Evaluation Centers

Within the NDE community there are very few other facilities that conduct research and testing similar to the work conducted at the FHWA NDE Center. However, there are many organizations in both America and abroad with which the NDE Center has collaborated and/or exchanged information. Some of these organizations include:

Example of Universities

- **Drexel University** - collaborated on bridge assessment techniques relative to short span concrete bridges in West Virginia.
- **Rutgers University** - worked with Rutgers on research related to ground penetrating radar for evaluation of bridge decks.
- **University of Vermont** - worked with the University of Vermont on research related to ground penetrating radar for evaluation of bridge decks.
- **John Hopkins University** – research related to steel NDE and Radiography.
- **University of Maryland** – research on radiography, shearography.
- **National Institute of Standards (NIST)** – worked with the NDE groups at both the Gaithersburg, MD and Boulder, CO campuses.

Example of Research Laboratories

- **Virginia Transportation Research Council (VTRC)** – research on both steel and concrete NDE.
- **NASA Langley NDE Center** – worked on review panel on NDE for Space Shuttle Return to Flight program.
- **Texas Research Institute (TRI)** - The Nondestructive Testing Information Analysis Center (NTIAC).

Example of Foreign Research Laboratory

- **Federal Institute for Materials Research and Testing (BAM)** - collaborated with BAM on deployment of an NDE compendium in America.

In addition, through the course of on-going research at the NDE Center, the staff at the Center has developed working relationships with a wide range of stakeholders including professionals at the State Highway Administration (SHA) level, in industry and in academia.

Vision for the Future

The vision of the NDE Center is to provide world-class advanced NDE research within the context of an integrated view of highway facilities which includes bridges, pavements and other structures such as culverts, retaining walls and tunnels. The key aspect of this vision for the NDE Center's future is to augment our research focus of concentrating on the internal elements of the highway bridge with that of global structural health monitoring (SHM) and seeing the bridge as a component in the overall highway system.

This expanded approach and perspective will, therefore, redefine the NDE Center's mission and objectives. Research on bridge elements, their deterioration and capacity, will always be at the heart of our research activities; but we will also seek to partner with and support other programs within the FHWA and to reach out to committees at TRB and AASHTO for collaboration on research needs and synergies. This transition will necessitate our partnering with various FHWA offices including the offices of Asset Management and Pavement. Our vision for this transition also involves collaboration and partnering with other interested parties.

Historically, the emphasis of research at the NDE Center has been on condition evaluations of bridges with some relatively minor research in pavement NDE. The bridge NDE research program has involved technology evaluation for quality assurance (QA) and quality control (QC) of new bridges as well as condition assessment of in-service bridges. The in-service NDE evaluation involves the performance of NDE as a result of the biennial visual bridge inspection program as well as special requests as identified by the highway agencies. The biennial inspection program is mandated by the National Bridge Inventory System (NBIS) which requires the FHWA to maintain for each bridge an informational database and to use the inventory data to help solve bridge deficiencies, to follow the results over the years, and to use this historical information as a basis for predicting future needs.

The NDE Center will still support its traditional customers while facilitating broader collaboration with other highway programs. The NDE Center will also investigate the potential for supporting states via pooled fund initiatives and teaming-up with individual states.

Improvement Strategies

Specific strategies are outlined below for improving the NDE Center's overall performance.

1. Goal of Research – the goal of research at the NDE Center should be to positively impact the Nation's highways NDE technology loop in ways that involve all components of the FHWA offices and industry's marketplace:

- Research, develop, and field test NDE system prototypes and, if proven promising, engage the FHWA Resource Center on their deployment. Field

testing can be performed in cooperation with the federal land offices. System prototypes should be developed in close cooperation with the industry.

- The FHWA Resource Center in cooperation with the division offices, should be engaged in the demonstration and training of the client stakeholders. Feed-back should be communicated back to the NDE Center for product improvements.

- Industry should find it feasible to manufacture the next generation field units after identifying client needs and market requirements from the interaction above.

- Consultants should be able to provide the service for a fee that the clients are willing to pay.

The goal is for the research products to be deployed to the stakeholders and for the NDE market to be positively impacted as the result of these efforts.

2. Multi-Probe Approach to NDE Testing – One main impediment to a more widespread deployment of NDE technology is data reliability. One way to reduce the false positives and false negatives and imaging artifacts inherent in many NDE test methods is through the use of multiple test methods. Multi-probe approach will enhance the capability of NDE for defect detection under differing field conditions. The emphasis should be for the NDE Center to be directly involved in the development of multi-probe systems, which requires system integration and data fusion, with automation/area scanning capabilities and advanced data visualization.

3. Multi-Phased Approach for NDE Test Program for the DOTs – NDE testing is often viewed as being too expensive, using equipment which is not field deployable and requiring advanced expertise for its operation. Consequently, most owner agencies do not have an active NDE program. In some NDE applications, an alternative model can be considered whereby the project is divided into three distinct phases:

- field data acquisition
- back-office data-processing/imaging
- data interpretation

Using this approach, the owner agencies can be involved in the purchase or leasing of testing equipment and be trained on the data acquisition phase only under the training and supervision of manufacturer or consultant agencies. The owner agency's investment is primarily on equipment purchases and operation using in-house staff rather than long-term investment on specialized personnel required for data analyses. Specialized data processing/imaging that requires such expert input is performed off-site by consultants using on-line transmission of the data. Once final images are obtained, data interpretation is performed by the consultant in cooperation with engineers at the owner agency.
In one project with the West Virginia DOT, the NDE Center has pursued this model wherein two levels of training are provided to the DOT: one at a technician level for the field personnel involved in data acquisition and a second executive level training for the

management team for understanding the final results. In this model, the costs of NDE projects are substantially reduced for the State as costly field mobilization for routine data acquisition by the consulting firm is not longer required. Data analyses and modeling is then performed by consultants off-site.

4. Outreach Program – NDE Web Manual – To improve customer service and to promote awareness and information collaboration, the NDE Center is in the process of deploying a web-portal called the "FHWA NDE Web Manual." The goal of the web manual is to present information in the format of engineering problem (application) to available NDE technologies. This manual will eventually develop into a volunteer-based program involving expertise from the research community and the industry. Therefore, a research panel will need to be formed for this program to facilitate partnering with the industry other government agencies. To aid in information dissemination, all previous work performed by the NDE Center will also be incorporated into this web manual.

5. Cross-Cutting Research –An important goal of the NDE Center is to develop a cross-cutting capability where NDE technologies are used to evaluate bridge superstructure (current emphasis) as well as bridge substructure, pavements, and structural health monitoring (SHM). Ideally, the Center should be structured to serve both offices within Infrastructure R&D.

6. Revised Test Procedures and Asset Management Practices – Most NDE systems developed at the NDE Center have been expert-run prototype units under the care of a lead researcher. Unfortunately when these personnel leave, the technology often sits on the shelf. Equipment procedures should be developed as work progresses and not as a final product. Documents detailing test procedures should be written such that an outside engineer or technician can read and successfully follow without requiring further instruction from other sources. The user manuals will be used for training both Center and other staff; internal cross-cutting evaluations; and training or demonstration purposes by the FHWA Resource Center to the clients.

7. Stakeholder Training Opportunities – As mentioned, the NDE Center should take a more proactive role with the FHWA Resource Center in training the clients and stakeholders and organizing demonstration studies. Possible avenues for these activities are National Highway Institute (NHI) courses, workforce training of the SHAs, and site demonstration projects.

8. Continual Capital Improvements - The NDE Center has just recently substantially increased the computing capabilities of the center through the purchase of two 8-CPU (16 cores) parallel processor computing units from the ThinkMate Corporation of Waltham, Massachusetts. Additionally, several new laptop computers and specialized software have been purchased. Several new testing equipment purchases and capital improvements are planned for the remainder of the calendar year.

Along with the initiatives outlined above, there remains the underlying goal of the NDE Center to work toward a better, broader, and more detailed and more useful condition

assessment of our highway facilities.

In summary, the vision for the laboratory is one of providing world-class advanced NDE research within the context of an integrated view of the highway facilities. Objectives to improve tools, methods, quality, efficiency and effectiveness in research services underlie the larger objective to view highway infrastructure such as bridges as what they are – one of many components that work together to provide safe, accountable, flexible and efficient transportation for our nation.

Roadmap for the Nondestructive Evaluation Center

The vision of the NDE Center is to provide world-class advanced NDE research within the context of an integrated view of highway facilities which includes bridges, pavements and other structures such as culverts, retaining walls and tunnels. Traditionally, however, the FHWA NDE Center role has been to conduct studies and provide technical assistance that mainly supported the overall FHWA Bridge Program Strategic Plan.

The primary goal of the Bridge Program Strategic Plan are to ensure that FHWA delivers a cohesive bridge and structures program that is responsive to National and stakeholder needs, and helps to ensure an efficient and safe network of highways throughout the United States.

The FHWA Bridge Program Strategic Plan has four primary objectives:

- Highway structures are designed, constructed, and rehabilitated with standards and materials that provide longer and more reliable performance

- Highway structures are constructed or rehabilitated with systems, methods, and practices that reduce congestion and improve safety

- Highway structures provide a high level of safety and service under all Conditions

- Highway structures fit their environment through the application of context sensitive solutions principles

Studies conducted in the FHWA NDE Center are therefore intended to support these objectives. The following roadmap provides an overview of current and planned activities that will be conducted at the NDE Center.

Current Activities

Current research activities at the NDE Center consist of nine separate projects utilizing six distinct sources of funding.

Table I-1. Current Research Project by Funding Source

Funding Source	Research Project
Program Funds Steel Bridge Testing	*NDE technologies* - for the detection of growing fatigue cracks in steel bridges
Advanced Research Funds	*Development of nonlinear dynamics (chaos theory) analysis* - for the condition assessment of highway bridges (with Dr. Livingston)
General NDE Funds	*Bridge Decks Evaluation* – evaluation and prototyping several state-of-the-art NDE automated imaging techniques for detecting delamination/ corrosion in concrete bridge decks
	Development of Web Manual and NDE Compendium - development and deployment of a web based manual related to NDE applications and capabilities. Some additional internal funds are also targeted.
	Development of a Falling Weight Deflectometer Imaging System for Pavements – new procedures for using FWD as well as incorporation of geophysical imaging tools for better subgrade characterizations
Pooled Funds	*Rapid Load Rating* - of West Virginia Bridges with Drexel University. Now at Phase III
	Pooled fund TPF-5(088) - NDE/NDT for Highways and Bridges with New York DOT (Dr. Sreenivas Alampalli, Lead) and others
EarMarked Funds	*Development of an advanced bridge deck evaluation technology* - utilizing GPR with University of Vermont (PERES II)
Internal Co-Op Funds	*Research with TFHRC corrosion experts Drs. SK Lee and Chong (now retired) to investigate* - 1) Corrosion characteristics of dowel bars; 2) Test effectiveness of slab membrane; and, 3) develop coating specifications. The NDE Center has also been active in work to support FHWA's investigations at the Central Artery Project

Planned/Future Activities

- Automated Ultrasonic Technology (AUT) Specifications and Phased Array Study - to further explore development of a specification for using automated ultrasonic testing in fabrication of steel bridges for incorporation by both American Welding Society (AWS) and AASHTO specifications; internal funds needed

- Activities in support of the Long Term Bridge Performance Program (LTBP) program. Periodic NDE inspections and instrumentation support

- Acitivities in support of the Exploratory Advanced Research Program (EARP)

- Planning a new pooled fund study with NCDOT for determining the unknown depth of bridge foundations

- Activities in support of 1) sponsoring and organizing the 2008 Structural Material Testing (SMT) Conference in Berkley, CA, 2) organizing a 2008 Workshop at TRB on periodic NDE for SHM, 3) other NDE related conferences and workshops.

The table below indicates the NDE Center's roadmap for anticipated funding levels during the current cycle of the US Transportation Bill, SAFETEA-LU—Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users. The intent is to maintain research continuity beyond Fiscal Year 2008. However, due to funding uncertainties and the lack of discretionary funds, funding commitments are not indicated in the subsequent fiscal years.

Table I-2 FHWA NDE Center Activities Roadmap for Funding (funds in thousands)

	Activity/Description	FY '08	FY '09
Current Activities	Program Funds - Steel Bridge Testing	$900	$900
	Advanced Research Funds (Chaos Theory)	$450	$100
	General NDE Funds (Deck+FWD+Web Manual)	$850	$100
	Pooled Funds (Rapid Load Rating)	$183	
	Pooled Funds (NDE for Highways & Bridges)	$50	$50
	Earmark (GPR-PERES)	$500	
	Internal Co-Ops	$50	$100
Planned/Future Activities	AUT Specifications and Phased Array for Shop Weld Inspection	$50	$50
	Long Term Bridge (LTBP) Support (Periodic NDE and instrumentations)	$50	$100
	Exploratory Advanced Research Program (EARP) Support	$50	$50
	New pooled fund study for Unknown Depth of Bridge Foundations	$100	$100
	Conference/Workshop Organization (SMT/TRB) Sponsorship & Support	$30	

Focus Issues

Background

The NDE Center was established in 1996 in direct response to directives from Congress for the FHWA to establish and operate a national center engaged in research related to nondestructive evaluation tools and techniques. Accordingly, to date the NDE Center has been engaged in a fairly broad range of research activities focused on evaluation and improvement of NDE tools that stakeholders could utilize. Despite the rapid advancements in NDE tools and systems over the last 10-15 years, some NDE users in both state and federal agencies and in the private sector have been reluctant to apply NDE tools for effective and reliable inspection of bridge structures.

Since 1996, there has been no specific funding targeted for NDE related research in the Highway Authorization Bills. Continued research at the NDE Center has been made possible through discretionary funds made available by FHWA managers who have deemed the work of the NDE Center necessary and useful in effective stewardship of the nation's bridges and highways. Research in areas such as NDE have been judged as relevant and necessary due to the aging of the nation's interstate system and the increased need for bridge assessment tools that are more effective, more reliable, faster and easier to use. Despite a universal consensus within both the stakeholder and industry communities that improved NDE tools are needed, the current SAFETEA-LU highway transportation bill provides essentially *no discretionary funds* to support NDE related research.

Simply increasing funding for NDE related research will not address the many others challenges that are impacting advances that needs to be made in the NDE area. For example, while the worldwide highway NDE research is fairly limited, there exists very little coordination and broad-based collaboration of efforts. While many opportunities are available to transfer and share technology gains, there are few in-line efforts for researchers to interact and cooperate with each other as research work is on-going. Within the FHWA NDE Center, the on-going research work has been negatively impacted by the lack of continuity in funding. The work related to NDE research requires a long-term perspective; and securing a steady source of funding for the work is needed. Finally, increasing the scope of research at the NDE Center to include pavement and geotechnical applications (as well as other structures in highway facilities such as tunnels, culverts, and retaining walls) would benefit the FHWA, the stakeholders, and the NDE community.

We would like to take this opportunity to ask the Peer Review Panel to provide suggestions and guidance on several challenges put forward as focus issues below.

Focus Issue One: Increased Scope of NDE Center

To date, the focus of work at the FHWA NDE Center has been on bridge structures. In part, this focus has been in response to specific needs identified within the FHWA and

the states. For example, a review of NBIS data identified deteriorated bridge decks as the most frequent structural condition resulting in a bridge being rated deficient. Accordingly, NDE related research was focused on tools and techniques to assist bridge owners in the assessment of concrete bridge decks. This work resulted in a series of research projects where capabilities of ground penetrating radar (GPR), impact echo (IE), and infrared thermographies (IR) were assessed. As a result of these efforts, improved bridge deck assessment tools have been made available within the NDE community.

In addition, over 100,000 of the approximately 600,000 bridges in the NBIS are rated as structurally deficient. A bridge can also be considered structurally deficient due to a low structural appraisal, or load rating. This problem is compounded by the number of bridges with a lack of plans and limited documentation, most notably unknown foundations that also impact the accurate rating for a bridge structure. The topic of rapid load rating of the undocumented bridges has also been an active research area at the center.

Applying effective NDE tools and techniques to the assessment of existing pavements appears to be a logical extension to the role of the FHWA's NDE Center. While some would suggest that preventing pavement failures is not as critical as identifying deficiencies in a bridge structure, deterioration and failures in pavements directly affect the safety of the roadway system.

Any insight and guidance that the Peer Review Panel can offer on an expanded role for the FHWA NDE Center would be helpful.

Focus Issue Two: Funding and Staffing for the NDE Center

Reductions in designated research funds have been experienced over the duration of the current contract for staffing and operation of the NDE Center. For the last two years of the contract, the FHWA has operated under continuing resolutions resulting in funding uncertainty. The uncertainty of continued funding for research programs like the NDE Center remains. Further impacting the funding issue has been the large number of earmark research projects which, when combined with reductions in designated research monies, have reduced the funds available for research at TFHRC. For example, an earmark research project related to ground penetrating radar (GPR) at a state university resulted in on-going research on GPR at the NDE Center to be discontinued.

One of challenges being faced by the FHWA is how to provide leadership to the State Highway Agencies (SHAs) in key infrastructure research areas and what reliable sources of funding can be utilized. Clearly one approach could be to leverage the in-place assets of the FHWA's NDE Center to support continued NDE related research which would be funded by SHAs through pool fund programs. Nominal investments by the FHWA could be combined with funds from SHAs to conduct targeted research on NDE tools and techniques that could benefit the SHAs. To facilitate the increased scope of activities at the NDE Center, an increase in staffing at both the federal and contractor level will be required.

Any insight and guidance that the Peer Review Panel can offer on increased staffing and funding for the FHWA NDE Center would be helpful.

Focus Issue Three: Coordination of Research Activities and Development of a National NDE Task Force

One of the roles of the FHWA's NDE Center has been to serve as a focal point for NDE related research in the area of highway infrastructure. However, the conduct of NDE related research continues in a somewhat fragmented and disjointed fashion. Within the FHWA, NDE related research has long been well coordinated. However, research work sponsored by other agencies and SHA's have not always been well aligned or coordinated with the FHWA or each other.

One of the other challenge areas that have been identified is the lack of collaboration in on-going NDE related research. While much effort is done to disseminate the results of research work after the research is completed, there is very little effort among current NDE related researchers to collaborate during the work. One of the roadblocks in this area may simply be geographical separation.

It is believed that there is a benefit from an effort by the FHWA to assist and possibly facilitate collaboration by NDE researchers. This assistance could come in several forms including:

- Monitoring and tracking the progress of on-going NDE related research
- Facilitating on-line workshops where researchers exchange information about their work in an informal venue
- Sponsoring short-term exchange programs where researchers visit other facilities and participate in on-going research

While the challenges of these efforts may be significant at first, will the improvements in terms of more effective research will ultimately benefit the entire NDE community.

It is also believed that there is a benefit to forming a National NDE Task Force to coordinate and facilitate NDE research related activities in the US. At issue is should this task force is one of the operational components of the NDE Center. The purpose of this task force can include *specific functions* such as:

- Tracking the progress of the highway related research
- Technical input, review, and improvement of the ongoing NDE Web Manual Project
- Discuss strategies for the more effective deployment of NDE technologies, such as the development of a hands-on practical NDE training course for the bridge inspector community
- Consideration of development of a highway NDE Service Directory Handbook

Any insight and guidance that the Peer Review Panel can offer on an expanded role for

the FHWA NDE Center in coordination of research activities and development of a National NDE Task Force would be helpful.

Resources

Human Resources Center

Overview of the NDE Center Staff

The staffing for the NDE Center consists of a combination of both FHWA staff and contract staff provided by the prime contractor. The current staff is listed below:

Table III – 1. NDE Center Staff

Name	Position/Organization	Telephone	Email
Frank Jalinoos	Program Manager for NDE FHWA	202-493-3082	frank.jalinoos@fhwa.dot.gov
Mark Moore	Project Manager for NDE Center WJE	202-493-3120 770-923-9822	mmoore@wje.com
Ali Rezai	Senior Research Engineer WJE	202-493-3119	arezai@wje.com
Shuang Jin	Senior Research Engineer WJE	202-493-3152	sjin@wje.com
Travis Green	Research Engineer WJE	703-641-4601	tgreen@wje.com
Brian Story	Senior Laboratory Specialist WJE	202-493-3121	bstory@wje.com
Paul Fuchs	Research Specialist FCI Consulting	202-493-3133	paul.fuchs@fhwa.dot.gov

Areas of Technical Expertise

Resident within the staff of the NDE Center is a broad range of technical expertise related to nondestructive evaluation of bridges and other structures. The following table summarizes the areas of expertise and capabilities for each NDE Center staff.

Table III – 2 Summaries of NDE Center Staff Expertise and Capabilities

Laboratory Staff	**Frank Jalinoos**	**Mark Moore**	**Shuang Jin**	**Ali Rezai**	**Travis Green**	**Paul Fuchs**	**Brain Story**
Organization	FHWA	WJE	WJE	WJE	WJE	FCI	WJE
Degree	MS	MS	Ph.D.	Ph.D.	MS	Ph.D.	AS
Expertise							
GPR	✓		✓	✓		✓	✓
Impact Echo	✓	✓		✓	✓		✓
Radiography							
Ultrasonic Steel	✓	✓		✓	✓	✓	✓
Infrared Thermography		✓				✓	
SASW /MASW	✓						
Eddy Current	✓			✓	✓	✓	✓
Concrete Ultrasonic Tomography	✓		✓				
Cross Hole Sonic Logging	✓						
Gamma Density Logging	✓						
Instrumentation		✓		✓		✓	
Numerical Modeling	✓	✓	✓		✓		
Structural Testing		✓	✓		✓		✓
Field Testing	✓	✓	✓	✓	✓	✓	✓
Foundations Integrity	✓						
Parallel Seismic and Borehole Methods	✓						

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Program Manager – Office of Infrastructure R&D

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Frank is the Program Manager of the FHWA-NDE Center at the Turner Fairbank research laboratories. He oversees a broad program in nondestructive evaluation (NDE) of bridge structures including load testing, numerical modeling, detecting cracks in steel bridges, corrosion studies, studying deck delamination and foundation depth and integrity studies.

Prior to joining the FHWA, Frank was with Blackhawk, a Division of Zapata Engineering, Golden, CO, where he was the Consulting Manager of the infrastructure testing services (ITS) group. ITS specialty was the nondestructive evaluation (NDE) of civil structures, application of geophysics for geotechnical engineering, and research.

As Principal Engineer at InfraSeis, Inc., Denver, CO, he was the Director of InfraSeis's nondestructive testing (NDT) and subsurface geophysical investigations. Selected projects included:

- Foundation Testing. QA/QC integrity logging of drilled shaft foundations from access tubes (Crosshole Sonic Logging (CSL)/three-dimensional crosshole tomographic imaging and 4-pi Gamma-Gamma Density Logging (GDL) and testing of drilled or precast concrete piles without access tubes (Sonic Echo Test (SET)).
- Pavement Testing. QA/QC testing of new and existing concrete/asphalt pavements (or runways) and base material for integrity, thickness, and physical properties.
- Three-Dimensional Underground Imaging. Subsurface two- and three-dimensional tomographic imaging of ground condition and underground structures (foundations, grouting piles, underground voids, etc.) between multiple pairs of vertical or horizontal boreholes.
- Utility Pipe Testing. QA/QC testing of new and existing water/sewer/industrial pipes for shape, integrity, and rehabilitation QA. Utility locator surveys. Forensic testing from small diameter pilot holes for locating obstruction to subsequent horizontal directional drilling (HDD) operation (damage prevention).

- Compressor Site Testing. Computation of the mechanical properties of soils above bedrock at compressor or earthquake-prone sites. Also, subsurface in-situ testing of soils without the drilling of boreholes using push probe technologies.
- Testing of Critical Civil Structures. Nondestructive Testing and inspection of bridges for integrity, scour, and unknown foundation depth. QC/QA/forensic testing of dams, earth structures, private/industrial buildings, parking structures for integrity.
- Vibration Monitoring. Vibration monitoring of bridges, large structures and historical buildings. Monitoring leaks underneath dams and construction sheet piles.
- NDT Instrumentation. InfraSeis, Inc. developed its own proprietary "full-waveform" Crosshole Sonic Logging (CSL) system in cooperation with Mount Sopris Instruments of Golden, CO. The CSL system is designed for logging drilled shaft foundations and slurry walls between water-filled plastic or steel tube pairs. In addition, the company fabricated a sonic echo/ultra seismic system for testing drilled shaft foundations and pre cast piles without access tubes.

Frank as a Senior Geophysicists at Olson Engineering, Inc., Golden, CO was involved in several areas of work related to NDE:

- Nondestructive Testing. Used sonic echo test (SET), ultra seismic test (UST), crosshole sonic logging, Impact echo test (IE), ground penetrating radar (GPR), parallel seismic (PS), and spectral analysis of surface wave (SASW) methods.
- Geophysical Testing. Used seismic refraction, crosshole seismic, and SASW methods.
- Research Activities. Co-Principal Investigator in the National Cooperative Highway Research Program (NCHRP) for the determination of unknown depth of bridge foundations. Co-Principal Investigator in National Science Foundation (NSF) project for the tomographic imaging of defects in concrete slabs.

As a Geophysical Consultant at Production Geophysical Services (PGS), Englewood, CO. He was instrumental in the software development in source deconvolution and three-component data acquisition and processing in support of petroleum exploration and civil engineering projects.

As a Senior Geophysical Software Developer at Digicon, Inc., Houston, TX he made significant contributions to the geophysical software development including tau-p analysis, surface consistent deconvolution and inversion. He also worked with software maintenance of Digicon's "DISCO" processing package.

At Bolt Technologies, Denver, CO he conducted Geophysical research and program development in surface seismic exploration, three component

seismology, and vertical seismic profiling (VSP). He also developed travel time tomographic imaging software using ART and SIRT algorithms and curved rays.

He was also a Research Geophysicist with the Department of Geophysics at Colorado School of Mines.

He has a Ph. D., 1995, (Incomplete due to lack of faculty interest in NDE; passed comprehensive exam) in Geophysical Engineering from the Colorado School of Mines, Golden, CO. He has a Master's Degree in Geophysical Engineering from Colorado School of Mines, Golden, CO. He also has a Bachelor's of Science in Physics from Connecticut College, CT.

Professionally, he is active in the Transportation Research Board (TRB) - AFF 40 – Dynamics and Bridge Testing Full Committee, the Transportation Research Board (TRB) - AFF 40 (1) Nondestructive Testing Subcommittee, the American Society of Nondestructive Testing (ASNT) - Infrastructure Research Committee, the International Association of Foundation Drilling (ADSC, Technical Affiliate), the Environmental and Engineering Geophysical Society (EEGS, Past Society Liaison Chair), and the Society of Exploration Geophysicists (SEG); Near Surface Group (NSG) of SEG.

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Program Manager

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Mr. Moore has a demonstrated experience in developing, managing and conducting scientific programs and studies. In the last 10 years, Mr. Moore has served as the Program Manager for the initial NDE Center project for the FHWA, Special Projects in NDE program, and currently serves as the Program Manager for the ongoing Special Project in Nondestructive Evaluation. His technical background in bridge inspection, research, and project management provide him with the necessary tools to effectively manage this worthwhile project for FHWA. Mr. Moore is a Senior Consultant in WJE. He has been employed with WJE since 1982. Mr. Moore is a 1979 graduate of Purdue University, where he received a Bachelor of Science Degree in Civil Engineering and a 1982 graduate of the University of Texas at Austin, where he received a Master of Science Degree in Engineering.

Mr. Moore has participated in a wide range of projects involving structural investigation, evaluation, and analysis of existing bridge and building structures. His structural investigation assignments have involved many types of reinforced concrete structures, structural steel systems, and pre-tensioned and post-tensioned structures. While his background experience includes a wide variety of assignments, his most recent experiences serving as Program Manager for the FHWA Special Project in Nondestructive Evaluation and the FHWA NDE Validation Center Project are particularly relevant to the TSNDE Project. As Program Manager for the Special Projects in Nondestructive Evaluation (and previously the NDE Validation Center Project), Mr. Moore is currently responsible for all project aspects including development of task order proposal work plans including identification of appropriate staffing, development of technical work plans, budgets and schedules. Additionally, Mr. Moore serves as the primary technical reviewer of all project reports and technical publications and presentations.

Previous to his work on the Special Projects in NDE, Mr. Moore served as the Program Manager for the FHWA's NDE Center project and was responsible for staffing, laboratory design and build-out, test bridge identification and instrumentation, maintenance of project records including cost/budget performance, quality assurance, and coordination of outside NDE consultant involvement. The NDE Validation Center

Project was initiated in 1996 with the goal of constructing and maintaining a state-of-the-art laboratory dedicated to the development and testing of NDE technologies with highway applications. After initiation of the Special Projects in NDE work, the ongoing efforts of the NDE Validation Center were merged into the ongoing Special Projects in NDE work. The NDE Validation Center Project represents the type of high quality research work that can be achieved using FHWA and WJE resources.

In 1992, Mr. Moore completed a seven year assignment as Principal Investigator on DTFH61-82-C-00079, "Structural Modeling for Autostress Design by Loading Through a Precast Deck." Under this assignment, Mr. Moore was responsible for a wide range of activities in support of the design, fabrication, and instrumentation and testing of the largest model bridge structure to be erected at TFHRC. In his other work with WJE, Mr. Moore has conducted field and laboratory testing on a variety of structural systems. Some of the major field test programs have included the over-water runway extension at La Guardia Airport, the supported roadway slab in the Lincoln Tunnel, and the Grand Concourse Avenue Bridge in New York City. In the structural laboratory, Mr. Moore has conducted testing on structural steel and reinforced concrete building elements.

Mr. Moore is a registered Professional Engineer in New York, Georgia, Florida, and Texas. His professional involvement includes the following committee assignments: American Concrete Institute Committee 423, Prestressed Concrete; Prestressed/Precast Concrete Institute Technical Committee on Bridges; Cable Stay Bridge Committee for the Post-Tensioning Institute; and Chair of the Grouting Committee for the Post-Tensioning Institute. Most recently, Mr. Moore has been active in the Technical Committee on Grouting for the American Segmental Bridge Institute and in that capacity has recently participated as an instructor at two ASBI sponsored grouting training programs conducted at the University of Texas at Austin. Mr. Moore has authored more than 60 technical publications and presented more than 80 technical dissertations at professional conferences and symposia.

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Dr. Rezai currently serves in the position of Acoustics Research Engineer at the NDE Validation Center. Dr. Rezai joined WJE in 1999 under the ongoing SPNDE contract. Dr. Rezai has the prerequisite experience in the application of Acoustics for the investigation of highway bridges. Dr. Rezai earned his Ph.D. degree in Engineering Mechanics from Virginia Polytechnic Institute and State University, his MS degree in Engineering Mechanics from University of Missouri/Rolla, and his BS degree in Mechanical Engineering from University of Missouri/Columbia. His skills and expertise are in the areas of acoustical NDE techniques including acoustic emission monitoring and ultrasonic testing, microwave NDE techniques including ground penetrating radar systems for bridge deck inspection, wave propagation, solid mechanics, fiber-reinforced composite material, and computer programming. At present, Dr. Rezai is the Task Order Manager responsible for a comprehensive program to assess an Automated Ultrasonic Testing system using the P-Scan system to inspect welds in bridge flanges and web plates during the steel bridge fabrication process. The objective of this ongoing study is to compare the performance of the automated P-scan system to conventional radiography testing. As part of this study and his other acoustics work, Dr. Rezai is experienced in the ultrasonic detection of cracks in metals and is familiar with the application of the American Welding Society inspection codes for welding including AWS D1.1. Structural Welding Code, AWS B1.10 Guide for Visual Examination of Welds, and AWS B1.11 Guide for Nondestructive Evaluation of Welds. Dr. Rezai has been actively involved in providing on-site engineering, laboratory and field testing, and evaluation of acoustic-based NDE technologies, and the research and development of new acoustic methods to be used in health monitoring and inspection of highway infrastructure including bridges. He has also recently worked on tasks related to evaluation of a Local Area Monitoring Acoustic Emission system and evaluation and testing of HERMES/PERES ground penetrating radar systems. He was also participated in the Visual Inspection study. Prior to joining WJE, Dr. Rezai enjoyed several years of academic teaching experience at Virginia Tech.

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Dr. Jin joined WJE in 2003 and his work has been in the areas of advanced nonlinear dynamics and nondestructive testing, modeling and simulation techniques for structural health monitoring and structural damage and failure analysis of highway infrastructures. Dr. Jin's previous experience included work as a Resident Research Associate at the National Research Council (1999- 2003); as a Research Scientist and a Post-Doctoral Fellow in two university research centers (1995-1999); as a Research Engineer at China State Shipbuilding Corporation, a major shipbuilding corporation; and at a machinery research institution (1982-1990). His past experiences include the investigation of many complexes mechanical and structural dynamics problems involving weapon systems, media structure interaction, vehicle-structure impact, seismic soil-structure interaction, nonlinear finite element modeling, analysis and simulation, systems with uncertain properties, simulation of ambient traffic flow loading and vehicle motions, and analysis of response data for structural damage detection. He has more than 20 research publications in international technical journals and conferences.

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Mr. Green currently works on an as-needed basis at the NDE Center. Mr. Green has earned his BS in Architectural Engineering at the University of Kansas and his MS in Structural Engineering at the Georgia Institute of Technology. Since joining WJE, Mr. Green has been involved in structural investigations, evaluations, load tests and repair designs on a wide range of structures including bridges. This work has included the evaluation of post-tensioned, precast, and conventionally reinforced concrete structures and structural steel framed structures. In the last year, Mr. Green has been involved in the design, detailing and analysis of the upcoming FRP reinforced box beam test being conducted at the NDE Center for the New York State Department of Transportation. Additionally, Mr. Green has recently completed the design of a detailed FRP reinforcing system for a post-tensioned structure. Mr. Green is proficient in a wide range of elastic and inelastic structural analysis programs including RISA 2-D and 3-D and SAP 2000. Mr. Green is also proficient in AutoCAD 2000 and the use of Architectural Desktop. During summer breaks at the University of Kansas, Mr. Green worked for an architect, a precast concrete plant and as a research assistant at the University of California at Los Angeles (UCLA). The Pacific Earthquake Engineering Research Institute (PEER) funded his research assistantship at UCLA. Also, Mr. Green was awarded the Ewart Scholarship to study architecture at Heriot-Watt University located in Edinburgh, Scotland during the 1995-1996 school year. While a research assistant at the Georgia Institute of Technology, Mr. Green performed large scale experimental testing on partially restrained composite, beam-to-column connections.

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Mr. Story joined WJE in 2002 and has been involved in a wide range of laboratory and field testing of nondestructive evaluation systems. In support of the laboratory and field test programs, Mr. Story has provided mechanical and electrical technical support including set up of test apparatus and instrumentation. Mr. Story has been involved with test programs to assess the performance and reliability of a variety of nondestructive evaluation systems including infrared thermography, ground penetrating radar, ultrasonic testing, and radiographic testing.

Prior to joining WJE, Mr. Story served in the United States Air Force as Weapons Specialist for the F-15 fighter aircraft. In this capacity, he was responsible for loading and maintaining munitions on the F-15. While in the Air Force, Mr. Story completed specialist training at the Aircraft Armament Systems Technical School and was then assigned to Seymour Johnson Air Force Base, Goldsboro, North Carolina.

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Dr. Fuchs currently is a Research Systems Engineer for the SPNDE. Dr. Fuchs is a graduate of West Virginia University, where he received a Ph.D. in Electrical Engineering (1995), M.S. in Electrical Engineering (1994), B.S. in Electrical Engineering (1992), and B.S. in Computer Engineering (1992). Dr. Fuchs' areas of expertise are related to instrumentation design and development. This includes software development for desktop and web applications, embedded system hardware and software development, embedded wireless systems, sensor and signal conditioning systems, data acquisition system design and development, signal processing and algorithm development, and hardware design. Work for the FHWA NDE Center involves design and development of custom prototype instruments related to testing of highway bridge structures. His most recent work at the FHWA NDE Center includes the following:

- *NDE Web Manual Development* - An NDE Center web site is under development. This development includes design of web page layouts and system database structures to store and present information.
- *Infrared System Testing* - Previous work at the NDE Center resulted in the development of an infrared (IR) bridge deck inspection system used to measure sub-surface defects. This system was recently tested on one of the NDE Center test bridges. Other thermography work includes testing with thermal NDE systems using active heating sources. This technology has been applied to the measurement of bridge coats to look for defects.
- *MTS System Repair* - The operation of the hydraulic loading facilities in the NDE Center load floor area was restored. Here the laboratory hydraulic power supply was repaired and several systems were repaired or added to the facility.
- *Eastern Federal Lands Equipment* - Instrumentation used measure deflection of bridges was prepared and provided to Eastern Federal Lands Highway Division (EFLHD). EFLHD has used this instrumentation to test bridges during their inspection process.
- *Steel Bridge Testing Product Evaluations* - Work has been completed related to the FHWA solicitation process related to the crack detection in steel bridges. This work includes preparation of work plans and participation in product demonstrations.

Since beginning his work at the NDE Center in 1997, Dr. Fuchs' most relevant experience includes documented experience in the design and application of Electromagnetic Acoustic Transducers (EMAT's), embedded computer hardware and software design, low-noise analog circuit designs specifically for EMAT's and infrared detectors, embedded wireless systems design, optical systems design, including interferometer design and integration of infrared detectors, cryogenic systems integration for infrared detectors, analog and digital circuit design, including printed circuit board layout, computer engineering and software programming, signal processing and algorithm development and sensor design. Dr. Fuchs has also conducted work with modulated laser measurement systems, and spread spectrum wireless communications, as required for this labor category. He also has demonstrated experience in the design of transducers and transducer circuits for civil engineering applications; field testing of bridges, including fatigue and load testing experience; bridge load rating; design and application of infrared systems; embedded computer/system design and software programming, and configuration and operation of data acquisition systems. Dr. Fuchs has also authored a number of technical papers and given numerous presentations on the subject matter described above.

Financial Resources

The overall operation of the FHWA NDE Center is facilitated through a Laboratory Support Contract issued by the FHWA. The current Laboratory Support Contract was awarded to Wiss, Janney, Elstner Associates, Inc. (WJE) in September 2002 and extends for a period of five years. Not included in the Laboratory Support Contract are the salaries of FHWA staff associated with the NDE Center, travel expenses for FHWA staff, and costs associated with heat, electricity, telephone, and computer network services at the Turner-Fairbank Highway Research Center.

The research work conducted at the NDE Center is organized in a series of task order assignments that are funded through the Laboratory Support Contract. The Laboratory Support Contract establishes a framework under which WJE provides staff and services to the FHWA. For each task order assignment, a specific scope of work is established and a corresponding budget is established. The task order budget is developed based on the estimated labor to complete the defined scope of work and estimates of material, equipment and travel expenses associated with the task order work. All work, equipment, materials and travel at the NDE Center is funded through the task order assignments.

Since the current Laboratory Support Contract was awarded in September 2002, a total of 15 Task Orders have been established. At present, five of those task orders are active to include two that are being managed by FHWA Headquarters and the remaining ten have been completed. A brief summary of the budgets and costs to date for each task order assignment is presented in Table III-3. Budget Summary and Costs. Note that these costs to date are through May 2007.

A summary of the work conducted in each of the task orders issued at the NDE Center since September 2002 is presented in the “Research Activities” Section. A review of the currently active task orders is presented in the “Planned Activities” Section.

Section 5202 of the Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) established the Steel Bridge Testing Program authorizing $1.25 million for each of the fiscal years between 2006 and 2009. After adjustments and Congressionally-required takedowns, actual funds appropriated in FY 2006 were approximately $883,000. Steel Bridge Testing is the only program that is funded under SAFETEA-LU.

Table III-3. Budget Summary and Costs

Task Order	Title	Start Date	End Date	Budget	Incurred Cost
1	Transition of the NDE Center Operations	9/1/2002	1/25/2005	$290,172.00	$281.005.90
2	Bridge Applications for Infrared Thermography	12/2/2002	2/24/2006	$563,920.64	$494,943.17
3	Testing and Development of GPR Systems	12/5/2002	1/25/2005	$228,791.08	$222,097.77
4	Ultrasonic Testing	12/2/2002	2/24/2006	$884,234.27	$684,652.77
5	Nuclear Methods for Nondestructive Evaluation	12/5/2002	1/25/2005	$298,713.45	$293,618.62
6	General NDE Laboratory Support	12/2/2002	3/24/2006	$1,306,091.46	$1,051,347.21
7	Laser Measurement Support for the Curved Girder Bridge Project	3/31/2003	9/30/2005	$64,734.38	$56,944.03
8	Nonlinear Dynamics Analysis Structural Health Monitoring	4/14/2003	9/8/2006	$1,196,235.91	$836,605.49
9	Using NDE Tools for Monitoring, Load Testing, Analysis and Structural Monitoring of Bridges	6/27/2005	12/31/2006	$226,000.00	$208,728.71
10	Steel Bridge Testing	3/27/2006	3/23/2007	$732,528.00	$418,907.32
11	Laboratory Support for NDE Related Studies	4/24/2006	4/27/2007	$130,000.00	$52,660.76
12	General NDE Laboratory Support	7/31/2006	8/31/2007	$425,510.94	$147,029.03

Facilities and Equipment

Facilities

Introduction:

The TFHRC represents the focal point for research activities within the Federal Highway Administration, United States Department of Transportation. The original Fairbank Highway Research Center was constructed in the 1940s and consisted of the Fairbank Building and the Annex Building. In the early 1980s the facility was expanded to include the Turner Building which provides additional research laboratories and offices.

In 1996, when the new NDE Center was being developed by the FHWA, the space allocated to the development of the Center existed at the Ground and Mezzanine Levels of the Annex Building at the TFHRC. At the Ground level of the Annex building, shown in Figure III-1, approximately one-half of the existing space was occupied by heating and cooling facilities for the Annex and Fairbank buildings.

Figure III-1 Exterior view of Annex Building – home of FHWA NDE Center.

Development Plan for NDE Center
A Development Plan for the NDE Center was prepared to define the scope of work for construction of the Test Control Center (TCC) and laboratory facilities at the TFHRC. As originally envisioned, the NDE Center was to:

- accelerate the development of nondestructive technologies
- establish credible parameters for the assessment and implementation of new and existing technologies

Functional Requirements for NDE Center
As part of the NDE Center, the NDE Laboratory including the TCC is required to support research activities and staff in both the NDE Center and other ongoing research related to structures and materials. Specifically, the new NDE Center Laboratory space is required to support the following activities:

1. NDE Center Laboratory and Staff
2. Storage of NDE Control Specimens
3. Storage of NDE Equipment
4. Testing of Structural Components on Structural Floor
5. Testing of Structural Components and Materials in Loading Frames
6. Office and Work space for Structural Laboratory Technicians

The specific requirements of each of these activities were described in detail in the Development Plan and are summarized in the following sections. In addition, the final design and planning of

the NDE Center laboratory space needed to consider short term changes of use that may occur. A discussion of these short-term modifications is also included as part of this report.

1. NDE Center Laboratory

The primary function in the Ground and Mezzanine levels of the Annex Building is the operation of the NDE Center. The existing Nondestructive Evaluation group at the TFHRC was to continue its current operations within the space allocated in the Fairbank Building. The staff and operations of the NDE Center were to operate from the laboratory and office space to be constructed within the Ground and Mezzanine levels of the Annex Building. At the Ground level, the NDE Laboratory space is approximately 59 feet by 67 feet in plan and is located in the southern most section of the Annex building. The Main Laboratory is shown in Figure III-2. In addition to the primary laboratory space, an L-shaped area approximately 24 feet by 40 feet in plan to the west was also included in the space allocated to the NDE Center.

Figure III-2. View of main NDE Laboratory.

At the Mezzanine level, the existing space included a single office in the southeast corner of the space and a separate office area along the north side of the laboratory space. Reconfiguration of the Mezzanine level, shown in Figure III- 3.

Figure III-3. Typical offices on Mezzanine Level.

2. Control Specimen Storage

A key function of the NDE Center is to evaluate through testing selected techniques, methodologies and equipment for nondestructive testing of highway structures. In support of this planned testing and evaluation effort, an inventory of control test specimens was developed and acquired, utilized, and stored as part of the project. It was anticipated that control specimens would include samples of structural steel, reinforced concrete, prestressed concrete, sections of pavement, and timber. The size of the individual specimens would range from small scale weld samples that could be easily carried by hand and tested on a table top work area to large scale structural components that could only be moved by crane or forklift and would need to be tested while on the floor or on cribbing. As a result, the storage area for the control specimens needed to accommodate a wide range of sample sizes, sample weights, and overall configurations including long and slender structural shapes and large sections of concrete beams or prestressed concrete girders.

Three areas were identified for storage of control specimens. The largest sample storage area is outside of the NDE Center in the existing specimen storage area located directly to the north of the new Structural Testing Laboratory.

The primary storage area for control specimens was to be in the Storage Area to the west of the laboratory space at the Ground level. In this area, which was inside and has minimal temperature control, the storage of control specimens was to include heavy-duty open metal shelving, storage racks, and pallet based storage. While the area was to be heated and cooled, the control of temperatures in this area would not be as precise as in the NDE Laboratory space due to the direct access to the outside environment from the service door and roll-up loading doors.

The third storage area for control specimens would be in a 12 foot by 20 foot enclosed storage room on the Ground level adjacent to the northeast entrance. This storage room was constructed as part of the remodeling of the existing space. Both temperature and humidity were to be controlled in this room. Control specimen storage in this room are primarily open metal shelving and are utilized for samples of structural steel welding, cracks in structural steel samples, and other defects in small scale steel and concrete samples.

3. Equipment Storage

As part of the work in the NDE Center, extensive use of testing equipment and tools is required. Not all equipment and tools however need to be utilized at all times in the laboratory.

Storage of equipment in the NDE Center includes both short- and long-term storage.

4. Structural Loading Floor

The main area of the existing laboratory at the Ground Level includes a reaction test floor to facilitate structural testing. Since completion of the new Structures Testing Laboratory in the Turner Building in 1982, the majority of structural testing is now conducted in that laboratory. The reaction floor at the Ground level of the NDE Laboratory in the Annex Building was in poor condition. As part of the construction of the NDE Center the existing damage and deterioration to the reaction floor was repaired. The scope of this work was limited to straightening of the steel plates at floor level, re-attachment of the existing steel plates to the underlain structural beams, and installation of new concrete topping slabs to restore the surface condition of the floor. No enhancements or modifications to the reaction floor were made to increase the floor capacity or change the overall dimensions of the reaction floor.

5. Structural Laboratory - MTS Loading Frames

Within the existing structural laboratory space at the Ground level of the Annex Building were a series of three loading frames for direct tension testing of specimens. The three loading frames, associated environmental control chambers, load controllers, hydraulic grip controllers, and hydraulic load maintainers were consolidated into the newly established MTS Test area in the southwest corner of the NDE Center. This equipment is frequently used and its operation must be maintained during operation of the NDE Center. During the construction of the NDE Center it was necessary to temporarily relocate this equipment to the Structures Testing Laboratory in the Turner Building to protect it from damage and permit its continued use by the Structures Group. In addition to the relocation of the MTS loading frames as part of the construction effort, the existing hydraulic pumps that supply these frames were also overhauled and repaired.

6. Structural Laboratory Technician Work Space

As part of the NDE Center construction, work space is provided for two Technicians assigned to the Structures Group. At the present time, Technician work space approximately 12 feet by 18 feet in plan exists on the Mezzanine level in the southeast corner of the Annex Building. This

space is to be converted to work space for the NDE Center and required replacement of the space currently utilized by the Structures Group. Within the MTS Laboratory space on the Ground level of the NDE Center, a dedicated Mezzanine level area was constructed to provide equipment storage and work space for the technicians in the Structures Group.

7. New NDE Center Space

For the NDE Center, a complete renovation for the space was designed and constructed. The renovation work was completed in 1997. The completed space is shown in the following drawings and with a few modifications represents the NDE Center Laboratory space as it exists today. Figures III-4 and Figure III-5 illustrate the floor plans for the NDE Center. On the ground level of NDE Center there are two NDE test areas that

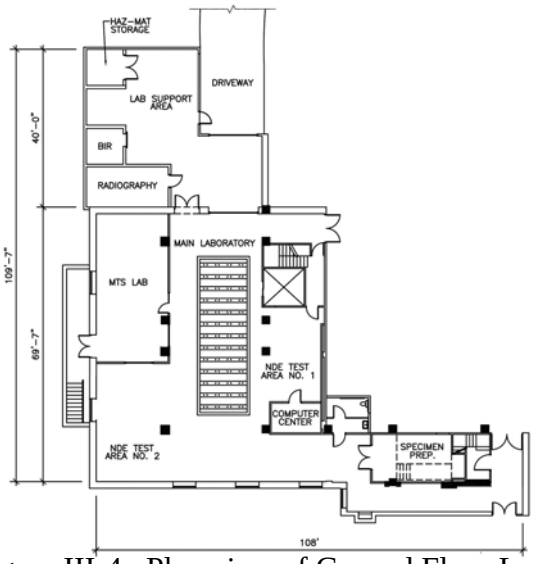

Figure III-4. Plan view of Ground Floor Level-Main NDE Laboratory.

provide ample space for specimen setup and equipment testing. In each of these test areas there are a series of laboratory tables and counters, storage cabinets, and electrical service and computer network connections. For both the NDE test areas, the configuration allows test specimens to be moved into the test area and bench-top testing conducted on the subject NDE system. Adjacent to NDE Test Area 1 is the recently installed Computer Room that houses the parallel processor computers used for the Chaos Theory modeling project. The structural laboratory floor in the middle of the NDE Laboratory serves to secure and test larger scale test specimens. Also on the Ground Level of the NDE Center is the Specimen Storage Room. This space serves as a central location for test specimens and is described in more detail below. The area dedicated for the BIR radiography imaging unit (also described below) is located on the main laboratory level and consists of both a Radiography control room and a secured area for the BIR equipment. The walls in this area are 16 inch thick reinforced concrete and provide shielding from x-rays for laboratory occupants. At the far back area of the main level is a 12 foot wide roll up door that provides direct access from the NDE Laboratory to the exterior for loading and unloading specimens and moving test equipment in and out of the laboratory.

The Mezzanine Level houses offices for six researches, one administrative assistant and has space for computer equipment and general office operations. The layout of the Mezzanine Level is L-shaped and is accessed via stairs or an elevator from the main level of the Annex Building.

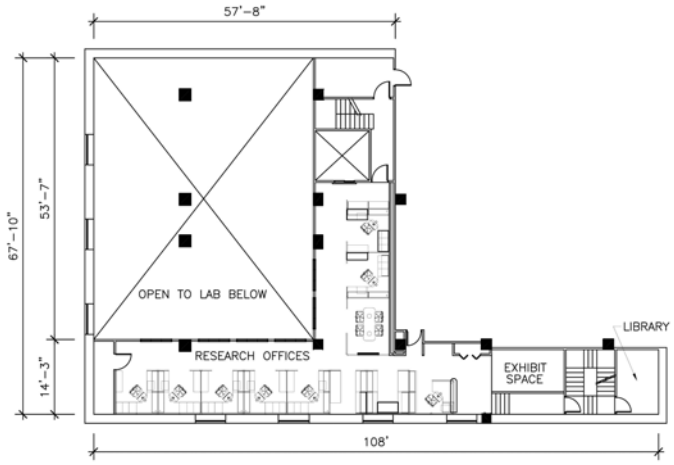

Figure III-5. Plan view of Mezzanine Level - NDE Center offices.

Another part of the NDE Center is the Instrumentation Laboratory. The NDE Center instrumentation laboratory, shown in Figure III-6, is used to design and develop NDE instrumentation. The laboratory is equipped with various electronic test equipment and facilities used in the design and development of specialized instrumentation. A 22-kip load frame is available for specimen and instrument testing. A wide variety of instrumentation is available at the NDE Center including ultrasonic equipment, thermal imaging systems, and specialized data acquisition systems. The Instrumentation Laboratory provides a resource to maintain and test this equipment.

Figure III-6. Instrumentation Laboratory.

The NDE Center is involved in the test and evaluation of a number of new NDE instruments and techniques. The goal of this program is to work toward providing better tools for bridge inspectors and other end-users of NDE instrumentation. Currently a number of innovative devices are being evaluated in both laboratory and field tests to better understand their capabilities and limitations.

Test Bridges

Essential to establishing the reliability of any NDE technique is a performance evaluation under actual field conditions. Bridge inspection conditions are unpredictable and are difficult to reproduce in the laboratory. For example, the unpredictable movements of traffic and accessibility constraints are very difficult to realistically duplicate in the laboratory. Further, any evaluation of an NDE system without including these situational factors will likely over-estimate the reliability. Field bridges provide a test bed for investigating the impact the inspection environment has on reliability and system performance. The field bridges are an extension of the NDE laboratory where additional variables affecting reliability can effectively be investigated. The test bridges also provide a medium for assessing the physical field suitability of NDE systems.

The selection of bridges for the NDE Center was completed after an extensive survey of all highway bridges within 400 km of McLean VA. This survey included both in-service and decommissioned bridges. In-service bridges were sought to provide an active environment where bridge inspections are normally performed. This allows many environmental and situational factors to be evaluated. Decommissioned bridges were sought to provide a test bed where defects of known size, location, and type could be introduced without violating the integrity of an in-service bridge while, at the same time, maintaining many of the situational factors that may affect NDE reliability. The general location of the test bridges is shown in Figure III-7.

Figure III-7. Location of NDE Center Test Bridges.

Two in-service bridges located near Washington D.C. were selected to be part of the NDE Center. These bridges have steel superstructures, multiple spans with less than 15 degrees skew, and are considered ideal locations to evaluate many NDE techniques. The Route 1 Bridge, shown in Figure III-8, is heavily traveled with a large percentage of truck traffic. This structure serves as an ideal location to investigate NDE systems intended to locate and size fatigue cracking as well as innovative sensors that detect load, stress, and deflection under live loading. The Van Buren Road Bridge, shown in Figure III-9, has an extremely low average daily traffic and allows easy access to the structure for extended periods without causing major traffic problems. The Van Buren Road Bridge is VADOT Structure # 609, and crosses the Quantico Creek, Prince Williams County, near the town of Dumfries, VA. The bridge consists of three steel beam spans with a bare concrete deck. The bridge was built in 1963. The inclusion of these in-service bridges as part of the NDE Center was accomplished through a cooperative effort with the VDOT.

Figure III-8. US Route 1 In-Service Test Bridge.

A third in-service bridge was added to the NDE Center list of structures in 2005 to provide a supplemental source of testing. The Carter Creek Bridge, shown in Figure III-10, is VADOT Structure #1011 and crosses Carter Creek at Route 200 (west of Route 3), Lancaster County, near the town of Irvington, VA. The Carter Creek Bridge is 288 feet in length and consists of five spans using steel beam construction and a bare concrete deck. The bridge experiences moderate traffic (6,500 cars a day).

Figure III-10. View of deck on Carter Creek Bridge.

Star Facility Bridges

In 1968, the Pennsylvania Turnpike Commission (PTC) abandoned an 18 km section of the Pennsylvania Turnpike. This 18 km section of roadway was preserved by the PTC for the purpose of providing a location for highway related research. This section of roadway, operated by the PTC as the Safety Testing and Research (STAR) facility, includes two tunnels, five bridges, and 18 km of four lane roadway. The NDE Center obtained permission from the PTC to use the STAR facility as part of its extended laboratory. The STAR facility provided an excellent resource for evaluating the effectiveness of NDE technologies under field conditions. The STAR facility bridges had many desirable qualities including conditions typical of aging infrastructure, are decommissioned which allows for structural modification of the bridges, and uninhibited access. An important part of the NDE Center was the test bridges used to conduct field trials of NDE systems and techniques. In 2003, the PTC stopped the STAR program and deeded the land and structures to a preservation group. Accordingly, the STAR structures are no longer available for use by the NDE Center.

Figure III-9. Elevation view of Van Buren Road Bridge

Component Specimen Inventory

Component Specimens: An important part of the NDE Center is an extensive collection of component specimens. Component specimens are small sections of highway structures (both with and without defects) that have been removed from in-service bridges or manufactured. The collection of component specimens is continually evolving as specimens become available from decommissioned bridges, are purchased from qualified vendors, or are manufactured in the NDE laboratory.

Component specimens allow NDE technologies to be tested in the laboratory to determine their capabilities. Laboratory trials on component specimens serve as the first step in evaluating NDE reliability. Since the component specimens contain well-characterized defects, they can be used to evaluate the accuracy and reliability of NDE technologies.

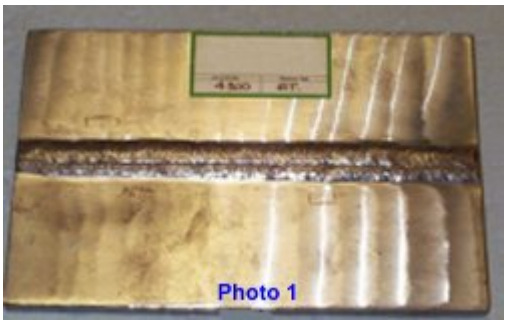

Figure III-11. Weld specimen plate.

Among the steel component specimens currently maintained by the NDE is an extensive library of welded details containing defects. A typical weld sample is shown in Figure III-11. Other steel specimens include pin and hangar assemblies and built-up riveted members. The specimen library maintained at the NDE Center is available to state and federal agencies, academia, and industries wishing to evaluate NDE technologies.

The NDE Center has also acquired a large group of "full scale" concrete component specimens. More than a dozen 6 feet by 12 feet reinforced concrete bridge deck specimens are housed at the NDE Center. These deck sections have a variety of thicknesses, reinforcement patterns, and topping materials. A typical slab section is shown in Figure III-12. An at-grade test pit is currently being constructed that allows mobile bridge deck evaluation systems to be driven over the specimens at normal operating speeds during testing. Other concrete specimens procured by the NDE Center include full sized prestressed box girders with broken and de-bonded strands.

Figure III-12. Large concrete slab samples.

Hardware

Dual Band Infrared Imaging System

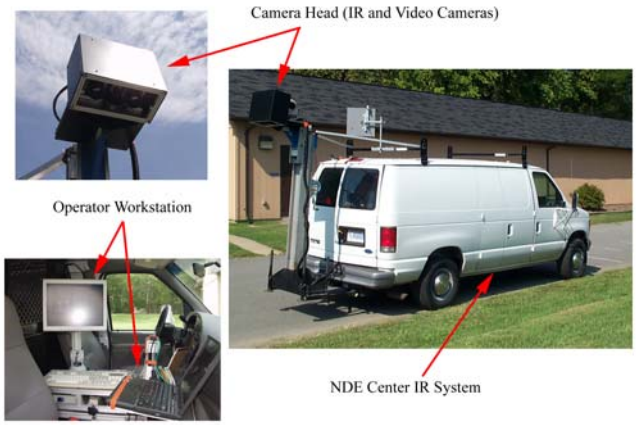

Figure III-13. Dual Band Infrared System on NDE Center Van in preparation for field testing.

The NDE Center Infrared (IR) System was designed to assess bridge decks in order to detect delaminated or debonded areas. The equipment is transported and operated in a passenger-sized van. A camera head assembly is mounted on the rear of the vehicle on a mechanical mount. Inside this assembly are two IR cameras, a video camera, and a vertical distance sensor. The IR system is shown in Figure III-13. All of the cameras are aligned to image the same area on the deck surface. The two IR cameras operate in different IR spectral bands, which allow the use of more advanced signal processing algorithms to extract features from the data. This system has the ability to collect and process data in a structured and organized manner. Instead of capturing free-running video images at 30 frames per second, individual frames of IR and video data are captured and referenced to the position of the system vehicle on the bridge. All data is stored in an internal system database. Both IR and video data can then be automatically fit together to form an image of the structure. In this manner, the location of a potential defect is known. The video data can be overlaid on the IR data for a more complete analysis of features in the thermal image, highlighting IR features caused by surface defects. Any section of data on a bridge deck can be quickly and easily retrieved and analyzed.

Non-contact Laser System

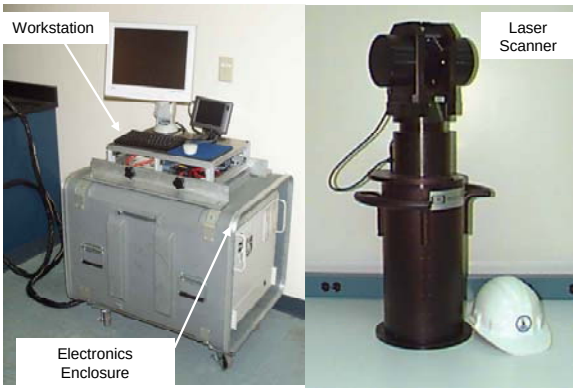

Figure III-14. Non-contact Laser System.

The NDE Center laser system has been used for various types of testing at FHWA since 1996. This instrument, shown in Figure III- 14, is essentially an extremely accurate, large-volume three-dimensional coordinate mapping device. Within the field-of-view of the instrument, the three-dimensional coordinates of a point in space can be found. The measurement laser can be scanned across the surface of an object and sub-millimeter accuracy measurements are easily achieved. Measurements can be made directly on a specimen surface without requiring special targets. The instrument is not affected by ambient lighting conditions and does not need to operate in a special environment. The laser system can make measurements with measurement accuracy less than 0.1 mm (0.004 inch) out of a total range of 24 m (80 ft). From one instrument position a very large volume can be measured. The system can make measurements directly on the surface of steel or concrete girders without requiring a special target, such as a photogrammetry dot, retro-reflectors, or probes. The system has been used in the field to measure deflections of bridge girders. The system has also been used as a laboratory tool to measure movement of large structural objects.

BIR Computed Tomography System

An x-ray computed tomography and digital radiography imaging system (pictured at right) is operated by the NDE Center and utilized by a wide range of researchers at TFHRC. The unit is shown in Figure III-15. The advanced computed tomography imaging system ACTIS 600/420 was built by Bio-Imaging Research, Inc. according to specifications provided by researchers at the NDE CENTER. The system consists of dual-focus 420-kV and microfocus 160-kV continuous x-ray sources. It includes two digital detectors, with a 512-channel linear array detector for tomographic imaging and a tri-field image intensifier with a digital camera for both real-time radiography and microtomography. The system can benefit many industrial and scientific applications, including materials research, non-destructive testing, core sample characterization, weld inspection, failure analysis, and reverse engineering. It is suitable for x-ray inspection of metallic and non-metallic items over a wide range of densities. The system produces cross-sectional computed tomography (CT) images, in-motion real-time radiography (RTR) images, and digitized radiographed (DR) images. In addition to density mapping, CT provides complete 3D morphology of parts with highly accurate dimensioning capability. The CT data sets can be converted to line drawings and exported as splines for solid modeling and comparison to Computer-Aided Design (CAD) drawings. Computed tomography also provides superior flaw detection capability of extremely small cracks, porosities, and voids that are normally not visible with film radiography inspection. The system can provide spatial resolution of up to 20 lines per millimeter or 25-microns. In addition, sample sizes up to a weight of 200-kg and a length of 100-cm can be accommodated. The system has been used by researchers at the NDE CENTER to conduct projects such as determination of air void parameters, crack propagation, and internal structure characterization of portland cement concrete and asphalt concrete structures

Figure III-15. BIR system for x-ray tomography.

20 kip MTS Load Frame

A 20-kip MTS load frame and controller are operational in the NDE Instrumentation laboratory and shown in Figure III-16. This load frame can be used for small scale load testing of systems. It is typically used to evaluate various NDE techniques that require varying loads on a specimen. The system is also used to calibrate sensors.

Figure III-16. 20 Kip MTS Load Frame.

Delta Therm System

This instrument uses the thermoelastic effect to measure the surface stress of a specimen. The thermoelastic effect takes place when a material's temperature changes as a result of experiencing a bulk compression or expansion. In order to measure the temperature changes on a specimen that result from stresses, infrared images of a specimen are taken while the specimen is subjected to a dynamic load. This instrument is useful for analysis of stress distributions around weld details on bridge structures. The system has the ability to measure actual stress distributions in structural members.

Figure III-17. Delta-Therm imaging unit.

Another related tool uses thermal NDE methods to examine specimens for defects. This system uses an infrared camera system in conjunction with a time-varying heat source. Changes in heat are applied to a specimen and measured with the infrared camera using special processing functions. This method can be used to detect subsurface defects in specimens, such as concrete, and can be used to detect debonds on bridge coatings. The system can also be used to detect cracks or other similar defects in steel bridge welds. Of particular advantage for this instrument is the ability to detect non-visible defects below surface coatings. The imaging unit is shown in Figure III-17.

HERMES Bridge Inspector System

The HERMES Bridge Inspector was designed to measure concrete bridge decks to determine and quantified delaminated areas. The system is a ground penetrating radar device that uses an array of antennas to collect a full three-dimensional data set of the internal structure of a deck. The system was designed to measure the concrete deck through an asphalt overlay. The system was also designed to collect data while traveling at highway speeds, thereby not requiring lane closures or disruption to traffic. The system was developed for the NDE Center by Lawrence Livermore National Laboratories (LLNL). The NDE Center has tested this equipment at many bridges sites all over the United States. The instrument was evaluated and assessed as to its ability to measure delaminations on actual bridge decks. The system was very successful at collecting three-dimensional data sets at high rates of speed (50-60 mph). Three-dimensional maps of concrete deck rebar were successfully produced. However, the system did not provide accurate measurement of a typical deck delamination. This system was the first to produce three-dimensional radar data on bridge decks. The development of this system helped private industry to develop commercial products with radar systems that produced similar three-dimensional renderings of specimens.

Figure III-18. HERMES bridge inspector surveying bridge deck at highway speed

Computer Systems

Computer Systems

The computer systems at the NDE Center can e grouped into three broad categories including:

1. Desktop Computers
2. Test Equipment Specific Field Computers
3. Parallel Processor Super Computers

The main focus for establishing the advanced computer server in NDE Center of TFHRC is to support the following four functions:

1. Large scale dynamics simulation of Finite Element models of highway infrastructure, using LS-DYNA MPP capability. The model size is usually large with 500~1000k elements with long dynamic response time history
2. Meshless computation for highway infrastructure crack detection problem, using LS-DYNA's SPH and GEF packages
3. Simulations of traffic flow loads, wind-rain loads for cable-stayed bridge, extensive nonlinear dynamics simulation for studies of chaos control of cable-stayed bridge vibrations
4. Data analysis covering wide range of advanced research and NDE tasks

The new parallel computing facility at the NDE Center has been constructed to support advanced research. The Computing Facility is shown in Figure III-19. The Parallel Processor facility includes the following components:

- **Hardware -** The hardware consists of a parallel computing machine manufactured by ThinkMate Corporation. The computing machine consists of two individual Units (computing boxes) clustered together. Each Box has eight dual processors (or 16 cores). Accordingly, the two-unit cluster is a parallel facility with 32 cores. The unit consists of two Opteron Workstation, each with 8 AMD Opteron 880 2.4GHz 2MB cache Dual Core processors (total 16 cores per unit). Each workstation has 8GB PC3200 DDR ECC registered RAM, a NVidia 7900GTX 512 MB PCI Express graphic card and total 6800 GB storage.

Figure III-19. Parallel Processor Computer Room.

- **Software-** The machines are configured under the Microsoft Windows Server Enterprise 2003 and Microsoft Computer Cluster Package (CCP) as two nodes (each with 16 CPU cores) to enhance the computational efficiency as compared to machines having more nodes but only 1 or 2 CPU cores.

- **Modeling Package -** The software consists of a MPP (massive parallel processing) version of a finite element program by Livermore Software Technology Corporation (LSTC) called LS-DYNA. LS-DYNA is a general purpose transient dynamic finite element program

capable of simulating complex real world problems. It is optimized for shared and distributed memory. A full Windows based license for up to 35 cores has been secured.

Since the system in TFHRC/FHWA is also Windows based rather than Linux based, the OS selected for this computer server (i.e., MS Windows Server OS) will allow TFHRC users to get quick access to such advanced computing equipment. In the past, the task for simulating structural response of a nonlinear finite element model of a typical cable-stayed bridge on a common dual processor PC has taken about 60 days (500k+ elements). It is anticipated that the simulation time can be reduced by a factor of at least 10-15 times (i.e., less than a week). Currently, TFHRC is planning to collaborate with the Argonne National Laboratory as part of the Transportation Research and Analysis Computing Center (TRACC) project. The objective of this project is to establish a high performance computing facility, known as the TRACC, and provide technical support for its use by DOT staff and their university and industry contractors. The result will be a national transportation supercomputing user facility to support DOT researchers and their contractors. The ThinkMate units can serve as a node in this advanced computing national network.

Additional Software

The following software is utilized at the NDE Center for the conduct of research activities and reporting of findings. All software utilized at the NDE Center complies fully with the current FHWA IT requirements.

Operating System for Desktop Computers - Windows XP Professional is used as the operating system for all desktop computers. Several of the desktop computers used for specific test equipment continue to operate under Windows NT. Microsoft Server 2003 Enterprise Edition is the operating system used on the parallel processor machines.

General Purpose Software - The NDE Center utilizes Microsoft Office 2003 for general desktop computer operations including word processing, spreadsheets, presentations, and general database applications, and Adobe Photoshop Elements 5.0 for editing photographs.

Other Applications - The NDE Center utilizes several other more specialized applications for daily work. These include Lab View, Mat Lab, Adobe Acrobat Professional 8.0, Adobe Acrobat Distiller 8, Surfer 8.0, Adobe LiveCycle Designer 8.0, ModTag, Microsoft Project 2007, dPLOT, LS-DYNA, AutoCAD 2000i, EndNote v7.

Acoustic Emission Monitoring System

Acoustic Emission (AE) monitoring is a nondestructive inspection technique that detects and evaluates acoustic waves generated in a material under stress. The acoustic waves are generated by AE sources within the material. Source of AE are predominantly damage related and AE monitoring leads the investigator to predictions of material failures. A typical AE source for steel is a crack that is growing due to applied stress. The crack releases a small amount of acoustic energy when interatomic bonds are broken and the crack propagates.

Figure III-18 shows Local Area Monitoring (LAM) system developed by Physical Acoustic Corporation (PAC). The LAM is a portable, rugged, and modular 8 channel system that operates on its own internal battery and/or AC power. The system can be controlled by direct interface via keyboard, monitor and mouse or it is used as a remote monitoring station with a PC computer connected via serial port cable or modems including wired and wireless modems. The LAM system was mainly designed to monitor the AE activities from known or suspected defects on small areas of a bridge. Examples of the type of applications suitable for local area monitoring include:

- determining whether a known or suspected crack is growing,
- determining if retrofits have halted crack growth,
- monitoring of a weld or connection point to assess structural integrity.

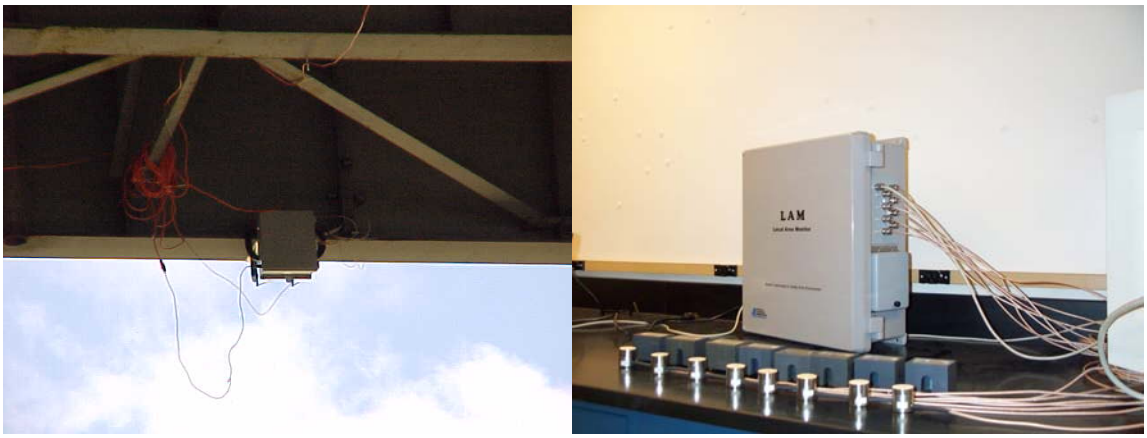

Figure III-18. Right picture shows LAM AE monitoring system with AE sensors and magnetic sensor holders; Left picture shows LAM is mounted on the bridge in the field to monitor existing crack for growth

Automated Ultrasonic Testing (AUT) System

After an extensive market search for the commercially available AUT systems, the NDE Center purchased an AUT system known as Projection Image Scanning (P-scan) system, manufactured by FORCE Technology, for the AUT project. The P-scan system was selected for the AUT project because it was capable of conducting an inspection that substantially conformed to the existing AWS Bridge Welding Code requirements.

The P-scan, shown in Figure III-19, is an integrated, computer-based, digital, ultrasonic testing and analysis system. The P-scan has three main components: the processor unit, the scanner module and the laptop PC platform. The data acquisition, digitizing and digital signal processing functions are all carried out in the P-scan processor unit. The manual scanner module is a position encoding device designed to record the position and rotation of the ultrasonic transducer during scanning. The laptop PC is used for data post-processing and graphical presentation.

The scanner module, known as the Manual Weld Scanner (MWS-1), includes a magnetic base that is attached to the steel plate adjacent to the weld being inspected. A scanner arm attaches to the magnetic base and has three degrees-of-freedom (DOF). The arm can rotate about the magnetic base, and extend along a linear bearing attached to the base. The rotation and extension of the scanner arm are recorded by encoders in the magnetic base such that the position of a transducer is defined in polar coordinates. A third DOF is provided at the end of the scanner arm where the transducer is mounted. The rotation of the transducer or skew angle is also recorded by an encoder. The positional data recorded by the encoders is combined with the time-of-flight information contained in the A-scan to determine the reflection location.

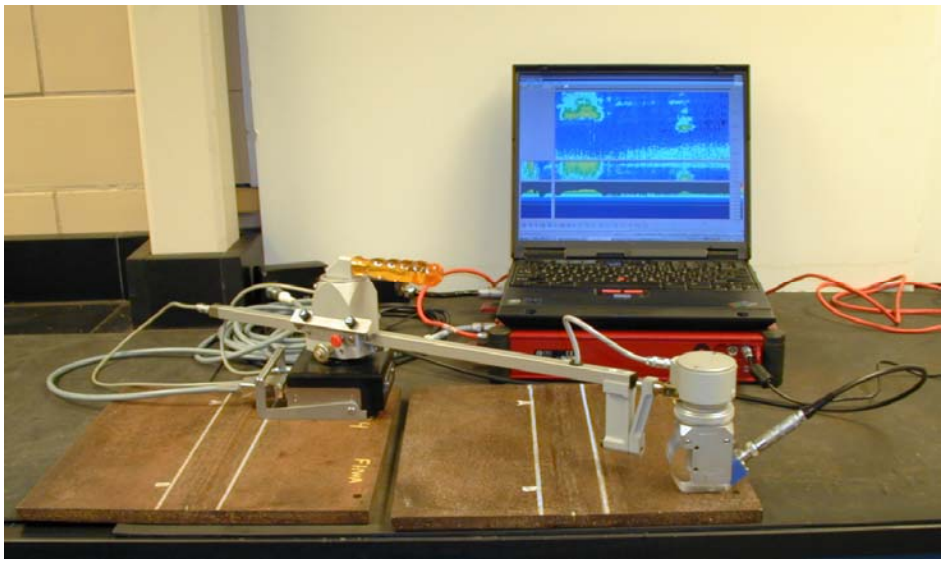

Figure III-19. P-scan system with its scanner module

The P-scan creates and displays a three dimensional perspective geometry of the discontinuity or defect detected in the weld on three projection planes. To illustrate this,

a laboratory specimen that has two implanted cracks; one at the toe of the weld and one at the root of the weld was scanned by the AUT. The image created by the P-scan, as shown in Figure III-20, clearly display all the geometrical characteristics of toe and root cracks in the weld.

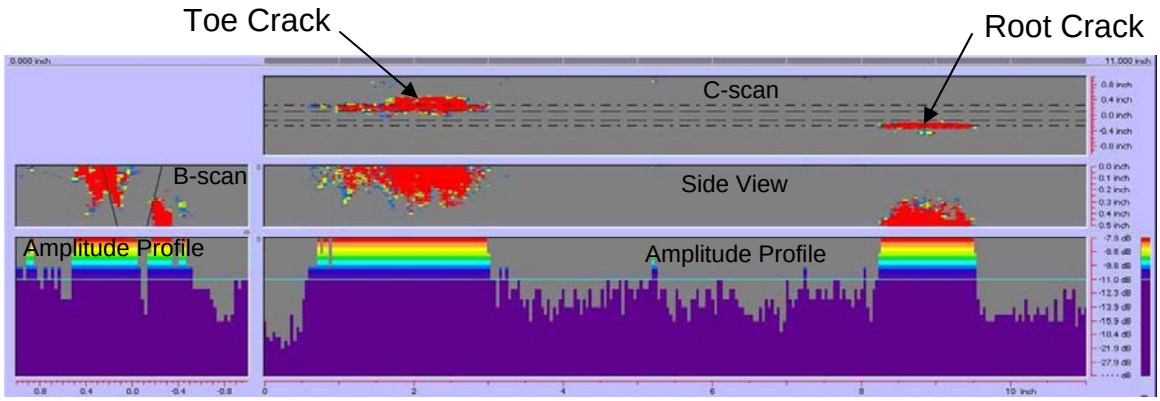

Figure III-20. P-scan images of the laboratory specimen with toe and root cracks.

Hand-Held and Field-Portable NDE Systems

The NDE Center has several hand held and field portable NDE systems that are used in the laboratory and field testing. These systems are briefly described below.

Conventional Ultrasonic Testing (UT) System - The NDE Center has a conventional ultrasonic testing (UT) system know as Ultrasonic Flaw Detector EPOCH III – Model 2300, which is manufactured by Panametrics Inc. The EPOCH, shown in Figure III-21, is a fully digital, light weight, field portable flaw detector that is equipped with a high resolution and electroluminescent display. The standard 12 volt battery pack provides eight hours of continuous operation and it can be mounted on a utility belt reducing the carrying weight of the EPOCH III to 2.6 pounds, light enough to be held and operated with one hand.

Figure III-21. EPOCH III Ultrasonic Flaw Detector is used for hanger pin inspection.

Eddy Current System – Eddy Current system is an effective NDE system for detecting cracks in metal structures. The system is non-contact and low cost that provides instantaneous test results. The NDE Center has a Nortec eddy current system shown in Figure III-22.

Figure III-22. Eddy Current Instrument inspecting weld in bridge girder

Dye Pentrant Equipment – Dye penetrant techniques are used to find surface breaking cracks on steel bridges. The NDE Center has the complete dye pentrant equipment that can be used in the laboratory and field for detecting surface cracks in steel structures.

Magnetic Particle Equipment – Magnetic particle testing can detect surface breaking cracks that are too small to be observed visually. This method can only be applied to ferromagnetic materials such steel. Figure III-23 shows the magnetic particle equipment.

Figure III-23. The magnetic particle equipment, AC Yoke and magnetic particles.

NDE Prototype / Demonstration Systems

The NDE Center has several pieces of equipment prototype systems that were delivered as part of research projects. Some of them are described below.

Alternating Current Field Measurement (ACFM) System – The ACFM system, Figure III-24, provides reliable detection and sizing of cracks in metallic components and can be used over paint, coatings and process related residue. ACFM inspection can replace magnetic particle inspection and yields equivalent sensitivity with the added benefit of being able to determine defect depth. This system has been used for a number of years in the off-shore oil industry to inspect for cracks in steel members.

Figure III-24. ACFM system

Electromagnetic Acoustic Transducer (EMAT) Strain Gage System – A research prototype, Electromagnetic Acoustic Transducer (EMAT) Strain Gage System, was developed for the FHWA to measure strains in steel. This prototype system, Figure III-25, was operated based on the commercially available EMAT transducer concept. The system was used to quickly measure stains caused by live-load in steel bridges.

Figure III-25. Electromagnetic Acoustic Transducer (EMAT) Strain Gage Prototype

Magnetic Flux Leakage System – The NDE Center has a prototype, Magnetic Flux Leakage System. This system was originally designed to inspect wire strands on cable-stay and suspension cables. Figure III-26 shows a specialized high-energy density magnets that was part of magnetic flux leakage system.

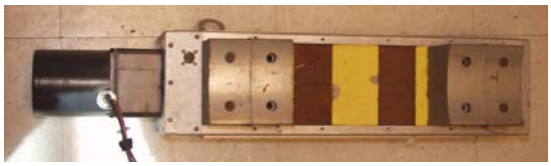

Figure III-26. Specialized High-Energy Density Magnet Assemblies

Research Activities

Recently Completed Activities

A summary of recently completed activities since September 2002 is presented below.

Task Order 1 - Transition of the NDE Center Operations

Start Date: 9/1/2002 End Date: 1/25/2005

The work in this transition period included research in the following areas:

- Infrared Thermography
- Ultra-wide Radar devices
- Automated Ultrasonic Testing
- Nuclear Methods
- Testing of Composites
- Sponsoring technical meetings
- Prestressing and post tensioned tendons

Task Order 2 - Bridge Applications for Infrared Thermography

Start Date: 12/2/2002 End Date: 2/24/2006

FHWA developed software for data acquisition and processing, developed necessary mechanical systems to support the system, arranged for necessary vehicle maintenance, and acquired hardware and software necessary to improve the system.

- Stress concentration at welded girder attachments was evaluated using the thermoelastic stress measurement system.
- A new system was developed for detecting cracks in steel bridges was tested in the laboratory and the field to determine its capability.
- Additional testing and development of the FHWA Laser Measurement System.

Task Order 3 - Testing and Development of Ground Penetrating Radar Systems

Start Date: 12/5/2002 End Date: 1/25/2005

FHWA continued testing the prototype HERMES II ground penetrating radar system. The effectiveness of the system for evaluating pavement thickness was tested at field test sites including TFHRC. Testing evaluated the ability of the system to define pavement thickness and delineate layers such as pavement and base. The system was also tested to evaluate its effectiveness imaging surface and subsurface cracking in concrete and asphalt pavements.

Task Order 4 - Ultrasonic Testing

Start Date: 12/2/2002 End Date: 2/24/2006

The work was subdivided into subtasks to facilitate project organization and coordination. FHWA continued efforts to test and evaluate automated ultrasonic test methods. This included field testing in fabrication shops and laboratory testing at the FHWA to include the following efforts:

- Additional shop testing was conducted as required to test the performance of AUT systems. This included additional testing at High Steel Structures and at the Stupp Brothers facility.
- FHWA interacted with the AASHTO/NSBA Steel Bridge Collaboration to transfer the results of the study, and provided input to efforts to modify the present welding code to include AUT systems
- The results of shop testing to date were compared with radiographic results.

Task Order 5 - Nuclear Methods for Nondestructive Evaluation

Start Date: 12/5/2002 End Date: 1/25/2005

FHWA supported the Advanced Research Team by conducting studies in the following areas:

- Prompt gamma/neutron activation (PGNA) measurement of chlorine and other elements in concrete. The primary objective of this work was to improve system performance and perform field and laboratory testing.
- Epithermal neutron spectroscopy of cement hydration. For the work in this area, a neutron detector array was calibrated using neutron time-of-flight, and proof-of principle testing was conducted in the laboratory. Following this work, a preliminary design of an integrated system was created.
- Potassium autoradiography using storage phosphor image plates. For the work in this area, image plates were calibrated, the image plate response to in-situ potassium was estimated, and image processing software was applied to evaluate results. Following this work, assistance was provided in field testing to evaluate autoradiography as a tool for the detection of delayed ettringite formation.

FHWA maintained and operated the FHWA X-ray tomography system. As part of this daily operation, research was performed using computed tomography (CT) for the evaluation of highway materials.

Task Order 6 - General NDE Laboratory Support

Start Date: 12/2/2002 End Date: 3/24/2006

This task supported the following activities:

- Testing and support to develop future projects at the FHWA NDE Center
- Feasibility studies of emerging technologies and proof-of-concept testing
- General maintenance of the laboratory equipment and maintaining laboratory conditions
- Providing laboratory demonstrations, presentations and tours for guests
- Assistance to other FHWA teams and participation/ general assistance to Center

customers
- General laboratory work

FHWA continued on-going efforts to test to failure a composite – reinforced box girder at TFHRC.

Conducted a proof of concept test using ground-coupled ground penetrating radar on a concrete bridge deck on the Dayville Road Bridge, Valdez, AK.

Other work in this task order included:
- The database for historic steel materials properties was updated and made available to the bridge community.
- Acquired and transported to the NDE Center two precast segmental box samples.
- Continued to assist the COTR in activities related to the translation of a German compendium of NDE techniques.
- Developed a written procedure for operating the tomography system.
- Developed a program for examining NDE methods for post-tensioned and prestressed structures.

Task Order 7 - Laser Measurement Support for the Curved Girder Bridge Project

Start Date: 3/31/2003 End Date: 9/30/2005

Efforts under this task order consisted of supporting the curved girder bridge project by providing instrumentation and laser measurements during field and laboratory testing to include:
- Measurements on full scale I-girder tests performed in the Structures Laboratory were completed. Measurements were required at multiple phases of testing and were coordinated with the work plan for the curved girder project.
- Measurements with the laser system were made during erection of a curved girder bridge near Philadelphia, PA. This work included preliminary planning and coordination activities and performance of onsite measurements at multiple times. This effort also included post processing of data.

Task Order 8 - Nonlinear Dynamics Analysis Structural Health Monitoring

Start Date: 4/14/2003 End Date: 9/8/2006

This work included analysis of structural response data, nonlinear dynamic 3-dimensional finite element modeling of structures, and simulations of ambient traffic loadings on bridges. Research work was continued on CTBR (Chaos Theory Analysis of Bridge Response Monitoring Data) analysis software for Bridge Structural Health Monitoring.

- The implementation of the Fractal Interpolation algorithm in CTBR software to improve the PDF (probability density function) computation from monitored bridge chaotic response data.

- Enhancements to the analysis, graphics, data I/O programs and functions for CTBR software.
- A User Guide, description of menus, and other documents for documentation of the CTBR bridge data analysis software was prepared.
- A set of data from the Fred Hartman Bridge was applied to the CTBR model.
- LSDYNA simulations of bridge dynamic responses were conducted for benchmarking the damage index in CTBR in bridge structural health monitoring analysis application.
- Improved sensitivity in chaos theory analysis of bridge monitoring data was developed. The bridge response from LSDYNA simulation of various bridges obtained in Item 1 above was used in CTBR structural health monitoring analysis to define the best data acquisition specification in sensor network SHM application. Additional efforts were needed to improve the sensitivity of the monitored data.

Task Order 9 - Using NDE Tools for Monitoring, Load Testing, Analysis and Structural Health Monitoring of Bridges

Start Date: 6/27/2005 End Date: 12/31/2006

Efforts under this task order consisted of using NDE tools for the monitoring, load testing, analysis and structural health monitoring of bridges.

In recent years, increases to legal load limits on the Nation's highways have resulted in questions concerning the load capacity of older bridges including reinforced concrete arch, slab and T-beam structures. Conventional load rating methods often yield conservative estimates of the capacity of these bridges and can result in posted load limits for the bridges. However, when controlled field testing of these bridges is conducted, the strength and stiffness of these existing bridges often exceeds the capacity predicted by conventional load rating methods using traditional codified parameters. Accordingly, there is an interest in using controlled load testing for determining the load rating of these bridges. Advancements in sensing technologies, simplified data acquisition equipment, and analytical tools used for structural analysis have also contributed to the increased use of load testing for rating of bridges. Further, easy to use load testing equipment allows existing bridges to be re-tested on a periodic basis to assess on-going deterioration.

WVDOT was concerned about the safety of the more than 100 old concrete arch, slab and T-Beam bridges on these CRTS routes. Plans and documentation for many of these bridges were not readily available, and information regarding their material properties and reinforcement detailing, other than that which could be assessed visually, were unknown. WVDOT's bridge and maintenance engineers were concerned about the capacity of these old bridges, and whether they could accommodate the significantly increased truck loading on an unlimited basis. Specifically, they were concerned about possible failures of these bridges due to overloading, and sought assistance from the FHWA to take advantage of advanced approaches for developing load ratings for these bridges through the use of diagnostic load testing.

Task Order 10 - Steel Bridge Testing

Start Date: 3/27/2006 End Date: 3/23/2007

Efforts under this task order consisted of facilitating development and deployment of nondestructive technologies capable of detecting surface or subsurface growing cracks as small as 0.01 inches in length or depth in steel bridge structures. The focal point for the study was on steel girders at fatigue prone, high stress, or critical detail locations where the presence of growing cracks was critical. Accordingly, locations with high concentration of stress, particularly at steel weldments and sharp corners were also of interest. The FHWA engaged in a series of contracts with developers and providers of crack growth detection technologies. The purpose of these contracts was to thoroughly assess the capabilities and limitations of each crack growth detection technology or system.

The work was subdivided into subtasks to facilitate project organization and coordination and is described briefly below:

- Prepared a detailed work plan for the laboratory work under this task order.
- Conducted a small-scale laboratory testing and evaluation of the selected NDE crack growth detection technologies.
- Performed a primary study on computational fracture mechanics analysis using the advanced Meshless Method in LSDYNA simulations for developing numerical models of the crack propagation in highway steel structures. characterizations.

Task Order 11 - Laboratory Support of NDE Related Studies

Start Date: 4/24/2006 End Date: 4/27/2007

Efforts under this task order included a range of activities to support several planned and on-going NDE related studies in the FHWA NDE Center. The work was subdivided into subtasks to facilitate project organization and coordination.

- *Dowel Bar Corrosion Study* - A series of corrosion tests on dowel bars embedded in concrete were conducted. The work in the laboratory included design and fabrication of the concrete forms for the test specimens, installation of the dowel bar elements, installation of corrosion monitoring equipment, and casting and curing of the concrete.
- *Membrane Stud* - The overall objective was to evaluate collectively new construction technologies and high performance materials to improve the durability of concrete bridge decks and helps to meet the 75- or 100- year maintenance-free service life goal. A series of test slabs was fabricated and membranes were applied. Once these specimens were completed, long-term durability studies were performed.
- *Preparation of Coating Specification* - A technical specification (or guideline) for a two-coat system over steel bridges to achieve optimum field was prepared.

Task Order 12 - General NDE Laboratory Support

Start Date: 7/31/2006 End Date: 8/31/2007

The work was subdivided into subtasks to:

- *Rapid Response of NDE Center Resources* - It was anticipated that the resources of the NDE Center would need to be deployed and made available to customers both within the FHWA and at the State level on an as-needed basis in the near future.
- *AUT Specifications and Phased Array Study* - The objective of this work was to further explore development of a specification for using automated ultrasonic testing in fabrication of steel bridges to be considered for incorporation by both AWS and AASHTO specifications.
- *Bridge Decks and Structures* – The work of this subtask focused on evaluation and assessment of imaging systems for bridge components. These bridge decks were surveyed using the FHWA-NDE Center infrared system: 1) Van Buren Bridge at the Prince Williams County, near the town of Dumfries, Virginia; and, 2) Carter Creek Bridge at the Lancaster County, near the town of Irvington, VA. In support of these tests, the existing dual band Agema (now FLIR) infrared thermography system was re-installed in the white van and readied for field testing.
- *NDE Center Computer Related Upgrades* - A series of computer related updates were implemented.

Planned Activities

The planned activities at the NDE Center have been recently re-organized into Task Order 16 and 17. The scope of each of these task orders is presented below.

Task 16 - Operations of NDE Laboratory and Conduct On-going Research

Task Order 16, began in July 2007. A team of WJE staff will be involved. Under this task order, the work currently defined in task orders 8-13 will be stopped. The operations of the NDE Center and the conduct of continuing research shall be carried out as follows under Task Order 16:

16.1 - Steel Bridge Testing

Research related to identifying and evaluating crack detection systems for use in steel bridges will be continued. This work was previously being conducted in Task Order 10. The research activities in this effort will include the procurement of test equipment, design and procurement of test specimens and conduct of the small scale laboratory testing program. Each of these activities is briefly discussed below.

a. Design and Fabrication of Small-Scale Test Specimens
WJE will design and fabricate a series of small-scale flat plate test specimens for laboratory testing and validation. The test specimens will be designed and fabricated using both in-house and outside facilities. It is anticipated that the test specimens will include a wide range of crack geometries, orientations, and depths in a range of material thicknesses. The test specimens will also include a range of coatings. The test specimens with weldments having artificially manufactured cracks, slags, porosities, and/or lack-of-fusions in the weld will also be designed and fabricated.

b. Preparation of Small-Scale Laboratory Testing Protocol
WJE will prepare a testing protocol for the small-scale laboratory evaluation of the NDE crack growth detection technologies selected under separate procurement. The protocol outlines laboratory testing procedures and guidelines, equipment demonstration, training the NDE Center staff to operate the system and conduct testing, scheduling of testing, the types and the numbers of test specimens. For each test procedure, the details of equipment set-up and calibration as well as the step-by-step test procedures will be carefully documented. Finally, the output from each system will be captured and documented.

1. Establish testing protocols for assessment of the technologies selected under separate government procurements.
2. Several NDE technologies procured under separate government contracts will be asked to participate in testing at the NDE Center on the test specimens using the guidelines and testing procedures set forth by the NDE Center. We will coordinate the scheduling of these initial laboratory trials.
3. Oversee the laboratory testing conducted by the participants. The testing will be performed in a controlled laboratory environment using test specimens with known cracks.

c. Small-Scale Laboratory Testing and Evaluation of the Selected NDE Technologies

WJE will facilitate, oversee, and conduct a small-scale laboratory testing and evaluation of the selected NDE crack growth detection technologies. NDE companies, selected under separate government procurement, will be contracted to demonstrate the equipment, train the NDE Center staff to operate the system independently, and deliver the system at the NDE Center so the NDE Center staff will have the sufficient time to familiarize themselves with the complete operation of the system. The NDE staff will conduct the laboratory testing under the supervision of the crack growth detection company staff. In each laboratory test setup, the NDE Center staff will carefully document the details of equipment set-up, the calibration, and the step-by-step testing procedures. Finally, the output from each system will be captured and documented. If, for a particular system, further post-processing of the collected raw data is needed, the company will supply the necessary equipments or software. During the execution of this task, WJE will complete the following efforts on this subtask:

1. Coordinate the scheduling of equipment demonstration, training of the NDE Center staff, and conducting small-scale laboratory testing and evaluation.
2. A report summarizing the laboratory test program and the performance of each crack growth detection technology will be prepared. This summary will provide documentation of the test specimens and testing procedures. The system set-up, operation, and testing procedures will be documented in an appendix. The performance assessment of each system will also be included in the report.
3. Several NDE techniques that are the best suitable methods of inspection for detecting growing crack in steel bridge structures will be selected for additional testing and evaluation.
4. Identify weaknesses and strengths of the selected systems.
5. Identify and document possible improvements for the selected systems for field deployment.

d. Application of Advanced Meshless Method with Fractal/fracture Mechanics in Study of Crack Propagation Problem in Highway Steel Structures

WJE will perform a primary study on computational fracture mechanics analysis using the advanced Meshless Method in LSDYNA simulations for developing numerical models of the crack propagation in highway steel structures. In particular, this investigation will be focused on revealing the capacity of the Meshless Method in LSDYNA to develop the practical numerical analysis methodologies applied to the micro-scale (to the range of 0.01 inches) crack propagation problem in general bridge steel girders, considering complex fractal crack boundary, dynamic loads and other common environmental characterizations. The main steps will include the following:

1. Numerical modeling and programming techniques for detailed fractal boundary descriptions based on fractals calculus theory. Interface code development in the fractal geometry characterization for LSDYNA meshless method simulations.
2. Application study on using advanced Meshless Method in LSDYNA simulation and fracture mechanics analysis of crack growth problem for highway steel structures. The techniques for LSDYNA's meshless method simulation for evaluating the growth rate of the small cracks in typical highway steel structures.

3. An investigation will be performed regarding the effectiveness of the Meshless Method in numerical evaluation of crack propagation problem from small-scale crack problem in highway steel structures.
4. Developing the required computer interface and numerical program for converting the results of LSDYNA Meshless Method analysis to other NDE field test quantities.
5. Application of the Meshless Method in LSDYNA simulations of test specimens including various types of crack geometries, orientations, and material defections.

16.2 - Advanced Research

Research related to the development of nonlinear dynamics (chaos theory) analysis for the nondestructive evaluation / condition assessment of highway bridges will be continued. Previously this work was being conducted under Task Order 8. This work will continue to include analysis of structural response data, nonlinear dynamic 3-dimensional finite element modeling of structures, and simulations of ambient traffic and rain and wind loadings on bridges. WJE will support the Advanced Research Team by conducting studies in the following areas:

1. Continue numerical simulations of Cape Girardeau Bridge (CGB) dynamic response.
2. Prepare a technical paper on 3-d simulations from the Cape Girardeau Bridge research for presentation in March 2007 at the SPIE meeting.
3. Continue work to obtain monitoring data from the Star City Bridge, WV and perform chaos theory analysis.
4. Obtain full data set for the Hartman Bridge and perform chaos theory analysis.
5. Continue to develop documentation of CTBR software.
6. Run numerical simulations of cable stay bridge vibrations using LS-DYNA.
7. Obtain monitoring data from Hartman cable stay bridge and analyze for chaotic behavior using CTBR.
8. Apply CTBR to monitoring data from UConn bridge monitoring network.
9. Evaluate the feasibility of applying chaotic control theory to minimize vibrations of cable stays.
10. Participate in Virtual Team for Structural Health Monitoring.

In general, the work on this technical directive is aligned in two broad areas as follows:

a. Research work on CTBR

Chaos Theory Analysis of Bridge Response Monitoring Data and analysis software for Bridge Structural Health Monitoring

1. The implementation of the Fractal Interpolation algorithm in CTBR software to improve the PDF (probability density function) computation from monitored bridge chaotic response data. Continued work on the following subtasks is anticipated.
2. Algorithm development with C++.Net and Measurement Studio code.
3. Computational efficiency improvements in fractal interpolation algorithm.
4. Code design in CTBR for using fractal interpolation in PDF evaluation.
5. Bridge data testing and graphic display in CTBR related to the fractal interpolation algorithm.

6. Enhancements to the analysis, graphics, data I/O programs and functions for CTBR software including the following:
    a. Optimization of C++.Net codes in CTBR.
    b. Improvement on reliability and accuracy of CTBR analysis functions.
    c. Improvement on bridge data I/O and processing path for CTBR analysis.
    d. Installation and distribution package of CTBR software.
7. Prepare a User Guide, description of menus, and other documents for documentation of the CTBR bridge data analysis software. This effort will include the following:
    a. Guide for chaos theory analysis of bridge response monitoring data including a description of the theory, principles and analysis steps.
    b. Preparation of a User Guide and menus for the use of CTBR software in bridge response monitoring data analysis: instructions, application steps and menus.
8. Apply a set of data from the Fred Hartman Bridge to the CTBR model. At this time, possible additional data sets include the following:
    a. Star City Bridge, West Virginia data.
    b. Cable-stay vibrations under wind loading.

To date, only one set of data has been made available from the Commander Perry Bridge. The additional data set from the Hartman Bridge will provide a much needed data set for verification of the CTBR program.

b. New Research and Development Work

1. Conduct LSDYNA simulations of bridge dynamic responses for benchmarking the damage index in CTBR in bridge structural health monitoring analysis application. This effort will include the following parameters:
    a. Nonlinear finite element modeling of highway bridges including multiple bridge structures, types and configurations.
    b. Simulations of multi-lane, multi-vehicle traffic flow bridge loadings and corresponding LSDYNA load curves.
    c. LSDYNA nonlinear finite element analysis of the bridges with different damage. Bridge dynamic responses for various damage cases will be collected and stored in a database.
    d. Bench mark work will be performed to determine the scale and the range of the damage index in CTBR from these bridge response data sets collected by LSDYNA simulation of the reference bridge systems.
2. Development of improved sensitivity in chaos theory analysis of bridge monitoring data. The bridge response from LSDYNA simulation of various bridges obtained in Item 1 above have been used in CTBR structural health monitoring analysis to define the best data acquisition specification in sensor network SHM application. Additional efforts are needed to improve the sensitivity of the monitored data. The following elements will be evaluated:
    a. Sensor installation location for bridge structural components, types and configurations.
    b. Sensitivity in chaos theory analysis in comparison to conventional linear analysis method. Effect of sampling time and environmental influence in chaos theory analysis of bridge response data sets for SHM applications.

16.3 - Internal Cooperative Research/ Corrosion Studies

This subtask will focus on NDE studies in support of internal TFHRC cooperative research studies such as structural health monitoring and on-going studies related to corrosion. Previous work under was conducted under Task Order 11 relating to corrosion studies. The following research efforts will be carried out as part of this subtask.

a. Membrane Study

Some surface barriers such as membranes and overlays are recognized to slow down penetration of water and chloride ions but we do not know exactly how these materials can contribute to long-term durability of the bridge decks under the actual service condition. In particular, thick coating type waterproofing membranes becomes popular, especially spray type and it is worth of investigating their effectiveness. Since the SAFETEA-LU legislation demands research on lightweight concrete and ultrahigh performance concrete (UHPC), the proposed membrane study will be combined into a single project by applying the waterproofing membranes over the lightweight concrete and UHPC slabs and carried out at the TFHRC. The objective is to evaluate collectively new construction technologies and high performance materials that will improve the durability of concrete bridge decks and help to meet the 75- or 100-year maintenance-free service life goal.

A series of test slabs will be fabricated and membranes applied. Once these specimens are completed, long-term durability studies will be performed. WJE will provide laboratory support for the fabrication and testing of the concrete slabs.

b. Coating Specification

A technical specification (or a guideline) for a two-coat system over steel bridges to achieve optimum field has been prepared by KTA.

16.4 - Preparation of Web Manual

This subtask will focus on tasks associated with development of the NDE Web Manual. Previous work was conducted under Task Order 12. The following research efforts will be carried out as part of this subtask.

Development of Web Manual and NDE Compendium

Develop and deploy a web based manual related to NDE applications and capabilities. The web based manual will serve as the focal point of the NDE Center's outreach program to FHWA and State DOT users of NDE. It is envisioned that the web-based NDE manual will provide users a tool to identify viable NDE tools for selected applications in highway and bridge infrastructures. The work will include development of the overall organizational structure for the web-based manual. The web manual previously developed for the geophysical area (http://www.cflhd.gov/geotechnical/) will be used as a guide for development of the NDE Web Manual. In the first phase the basic framework for the manual will be developed and the basic components of the manual will be populated with existing NDE related materials. In this first phase common NDE applications will be addressed including visual examinations, physical sounding, magnetic particle inspection, dye penetrant inspection and ultrasonics. In Phase two, the manual will be expanded to include more specialized NDE techniques including ground

penetrating radar, radiography, and thermography. In the third phase, contributions from academics and industry will be solicited and added to the resource.

For the NDE Web Manual, it is anticipated that the technical material will be developed and created by current staff at the NDE Center with the help of outside consultants. The resources of the Research and Technical Services Office will be utilized for creation of the web based documents and implementation of the manual on the web.

Work on the NDE compendium will also be completed as part of the work of this technical directive. The NDE compendium, originally developed by BAM will be translated to English and updated. The updated compendium will be prepared in an electronic format, fully searchable, and deployed as an electronic document. A technical editor will be retained from Rutgers University to assist with review of the revised/updated components.

16.5 - General Laboratory

a. Administrative and Marketing Support for the NDE Center

Administrative support staff will be made available on an as-needed basis to support the on-going activities of the NDE Center. Duties will include:

1. Provide assistance in display and poster materials to showcase the activities and capabilities of the FHWA NDE Center.
2. Participate in planning and coordination of on-site and off-site meetings related to the work of the NDE Center. Schedule and coordinate visitors to the NDE Center. Assist the FHWA Program Manager is developing an informative tour of the NDE Center.
3. Provide assistance to the FHWA NDE Program Manager related to preparation and editing of NDE related documents and materials.
4. Provide secretarial support to NDE Center staff related to technical and administrative tasks including word processing and preparation of presentation materials.
5. Monitor and maintain supply of office related materials needed to conduct the work of the NDE Center.
6. Monitor and coordinate facilities support for the NDE Center including routine cleaning, HVAC, and lighting.

It is anticipated that the Administrative staff will be available to the NDE Center through existing staff in WJEs Fairfax and Atlanta offices.

Marketing support staff will be made available on an as-needed basis to support the on-going activities of the NDE Center. The duties will include:

1. Updating of NDE Center logo.
2. Updating of existing on-site displays at the NDE Center.
3. Preparation of informational literature describing the on-going activities of the NDE Center.
4. Other marketing and out-reach efforts as requested by the FHWA COTR.

b. General Laboratory Activities

1. *Rapid Response of NDE Center Resources* - It is anticipated that the resources of the NDE Center may need to deploy and made available to customers both within the FHWA and at the State level on an as-needed basis in the near future. To facilitate these

activities, available time, equipment expenses and travel expenses are allocated under this Technical Directive. Deployment of NDE Center resources under this subtask will be at the approval of the COTR.

2. *Specialized Projects in NDE* - In support of the on-going NDE related research activities, a series of specialized projects are anticipated. Example projects include:
    a. AUT Specifications and Phased Array Study - The objective of this work will be to further explore development of a specification for using automated ultrasonic testing in fabrication of steel bridge that can be considered for incorporation by both AWS and AASHTO specifications. In support of this effort, the NDE Center will conduct a series of meetings with FHWA, AWS and other welding experts to define the parameters for the proposed specification to address the use of automated ultrasonic inspection in steel bridge fabrication. A draft modification to the current AWS specification for ultrasonic testing will be prepared and distributed for review and comment within the welding and bridge fabrication industry. Following the development of the proposed specification for the use of automated ultrasonic testing, a proposal for a specification change will be prepared and submitted to AWS. In addition to the efforts to develop a specification that addresses the use of automated ultrasonic testing techniques, the use of phased arrays will also be explored.
    b. A system will be developed to image concrete deck systems (GPR)
    c. Development of a falling weight deflectometer system for pavements
    d. Unknown foundations
3. *Equipment Assessments and Procurement* - In support of the on-going research activities at the NDE Center, selection and purchase of new NDE related equipment and computer equipment will be carried out in response to specific requests from FHWA.
4. *Capital Improvements at NDE Center* - The design and construction of capital improvements to the NDE Center will be accomplished as required.
5. *Travel Support and Sponsoring Technical Conferences/Workshops* - Invitational travel will be supported for attendance of state DOT staff at upcoming NDE related technical conferences. Sponsoring of technical conferences will also be provided.
6. *Graduate Student Support* - It is anticipated that graduate students in NDE related fields will be supported for focused research topics at the NDE Center.
7. *Training Course on NDE for Bridges* - A training course for state DOT staff on nondestructive evaluation techniques will be developed. This course will be made available to state DOT's for training of their staff.

Future Activities in Task 16.5

- *AUT Specifications and Phased Array Study* – This study will further explore development of a specification for using automated ultrasonic testing in fabrication of steel bridge for incorporation by both AWS and AASHTO specifications (internal funds).
- Activities in support of LTBP program (Periodic NDE inspections and instrumentation support).
- Acitivities in support of Exploratory Advanced Research Program (EARP).
- Planning a new pooled fund study with NCDOT for determining the unknown depth of bridge foundations.

- Activites in support of 1) sponsoring and organizing 2008 SMT conference in Berkley, CA, 2) organizing a 2008 workshop at TRB on periodic NDE for SHM 3) other NDE related conferences and workshops.

Task 17 - Pool Fund Studies

It is anticipated that a team of WJE staff will be involved in the conduct of Pool Fund Studies related to NDE for highway bridges. The work of the pool fund studies will be principally carried out by subcontracted researchers and WJE will provide project management for these subcontracts.

17.1 - Rapid Load Testing Pool Fund Study

The objectives of this research is to develop an experimental tool capable of (1) being employed in a widespread manner as a screening technique for undocumented bridges and (2) providing quantitative data that can be correlated with the condition of undocumented bridges. The research in this subtask will be carried out by Drexel University under an existing subcontractor agreement with WJE. Previously, this work was performed under Task Order 9.

a. Description of Concept

The concept for the envisioned experimental tool is an extension/modification of the Falling-Weight Deflectometer (FWD) technology from pavements to bridges. The FWD is an NDT device that is used for testing pavements for rehabilitation projects, research, and to detect pavement failures. This device applies dynamic loads to the pavement surface, similar in magnitude and duration to that of a single heavy moving wheel load, and captures the response of the pavement system over a given area using seismometers.

In previous phases of this research, proof of concept testing was conducted along with four truck load tests (and associated analytical modeling) of two reinforced concrete bridges along the Coal Resource Transportation System (CRTS) in WV. The objectives of these tests were to (1) accurately characterize the behavior of the test bridges, (2) determine the safe load capacity of the test bridges, and (3) forecast the estimated safe load carrying capacity of the test bridges into the future (based on the established salient behavior mechanisms). The secondary objectives of these phases were to investigate more rapid and cost-effective means of assessing the condition and capacity of undocumented bridges through (1) examining the feasibility of current off-the-shelf wireless data acquisition systems, and (2) performing proof-of-concept tests of a rapid bridge assessment procedure which leverages a pavement Falling Weight Deflectomer (FWD). The two structures included in this study were identified by WVDOT officials and included a simply-supported two-span reinforced concrete slab bridge and a single span reinforced concrete arch bridge.

While the use of wireless data acquisition would greatly reduce the time associated with load testing bridges, the current systems require further development before they can be reliably and safely used as the primary means of acquiring data during a load test.

The use of a FWD as a rapid screening technique for bridges was found to hold great promise. The results of the proof-of-concept testing indicated the ability of the FWD to induce sufficient impact to allow the acquisition of high quality response data that can be used to establish the deflection basins of even short and very stiff bridges.

Given the potential time and cost savings associated with wireless data acquisition, continued partnership with industry is recommended. It is the opinion of the authors that given the deficiencies associated with the current system, this type of partnership may be required for several years until the deficiencies are overcome and a viable market can be established.

Based on the positive results of the proof-of-concept study, the authors recommend that the development of a prototype FWD screening tool be given top priority. Given the time and resources associated with load testing and the number of bridges along the Coal Resource Transportation System, the only feasible means to comprehensively address this problem is through the development of a rapid screening approach. Once developed this may be leveraged to supply quantitative response data for the entire population of CRTS bridges and thus provide more effective means of leveraging the rigorous load testing procedures.

The proposed next phase of this research was conceived in direct response to these recommendations and will build upon the experience and expertise gained throughout the earlier phases of work.

b. Planned Work

The following provides a list of the salient tasks for the research:

1. *Research and Mitigate Existing Issues with the Current WVDOT FWD* – Investigate methods for eliminating weight rebounds and for outputting force time histories from the FWD's native load cell. The primary constraint for these methods will be the requirement that the current pavement testing capabilities of the FWD be maintained. (July 2007 – September 2007)
2. *Modify Current WVDOT FWD* – Implement the modifications designed and selected during previous effort. (September 2007 – October 2007)
3. *Initial Testing and Validation of Modified WVDOT FWD* – Conduct both crawl-speed truck test and FWD tests on two bridges selected by WVDOT. The validation will be performed by identifying modal parameters and ultimately modal flexibility from the FWD tests, and then comparing with the results of the crawl speed tests. (October 2007 – November 2007)
4. *Development of Real-time Data Processing and Visualization* – Develop software and analysis tools for real time processing of data collected using the FWD. This task will make use data from the physical bridge model located at Drexel University as well as the data generated through previous efforts. (July 2007 – December 2007)
5. *Interim Report* – Develop and submit and interim report. (January 2008)
6. *Additional Modification, including the Implementation of Real-time Data Processing and Visualization, within the WVDOT FWD* – Based on the results of previous efforts, identify any additional modifications required for the WVDOT FWD. Implement these

additional modifications as well as the real-time data processing and visualization capabilities. (January 2008 – March 2008)

7. *Final Testing and Validation of Modified WVDOT FWD* – Conduct both crawl-speed truck test and FWD tests on four bridges selected by WVDOT (including the two bridges included in early phases of the work). The validation will be performed by identifying modal parameters and ultimately modal flexibility from the FWD tests, and then comparing with the results of the crawl speed tests. (March 2008 – May 2008)
8. *Final Report and Training of FHWA and WVDOT Personnel*. (June 2008)

17.2 - NDE Pool Fund Studies

a. Structural Health Monitoring Study

The objective of the proposed work is to establish an automated structural health monitoring system through placement of permanent network of fiber optic sensors. The proposed work will be conducted by researchers from the University of Illinois - Chicago (UIC). The proposed study is centered on installation and monitoring of a series of robust sensors in the Patroon Island Bridge on I-90 in New York.

This research will facilitate the work of NYSDOT personnel for monitoring the status of the existing cracks in the Patroon Bridge and their growth. The monitoring systems will allow the NYSDOT with the capability for frequent and continuous monitoring of the bridge condition. The automated system enables the assessment procedures to be performed instantaneously and in real-time without interrupting the traffic. The NYSDOT has increased the frequency of the inspections for the Patroon River Bridge due to concerns regarding cracks at several locations including in the details of the floor beams–to-deck truss connections. The bridge is a main thoroughfare and it is made up of many hard-to-reach sections which require access for proper inspection of cracks and other anomalies.

The work under this pool fund will be managed through the NDE Center and the technical work will be subcontracted to UIC. WJE will provide overall project management of the pool fund study. UIC will be responsible for preparation of all reports. The estimated duration for this work is nine months including two months to setup and install the system, five months of monitoring, and one month to prepare the final report.

b. On-going Development and Maintenance of Web Manual and NDE Training

In support of the initial development of the NDE Web Manual and NDE Training course, on going efforts to continue to expand and enhance the web manual and training course will be conducted as funds are made available. It is expected that additions and enhancements to the NDE Web Manual and NDE Training Course will be needed in response to input from stakeholders and other FHWA organizations.

Project Briefs

Since the NDE Center was established in 1997, the Center has been responsible for the conduct of many significant research studies. The following briefly describes each of the studies to date and the technical significance of each.

Multisensor and Automated Measurements of Condition of Two Concrete Bridge Decks

The NDE Center in collaboration with the University of Vermont and Rutgers University evaluated the performance of several different measurement techniques for assessing the condition of reinforced concrete bridge decks. Two bridges in Virginia were the subject of the study. The first bridge was the Carter Creek Bridge in Irvington, VA. Figure IV-1. The second was the van Buren Road Bridge in Dumfries, VA. The intent of the study was a direct comparison of various NDE instruments and measurement techniques. The testing compared six different methods: 1. Visual inspection and photographic recording of position as shown in Figure IV-2; 2. Half-cell electrochemical potential; 3. Impulse type multipoint scanning ground penetrating radar; i.e. the HERMES/PERES II system; 4. Step-frequency multi-antenna ground penetrating radar; 5. Chain drag; and 6. Impact echo infrared thermography. Each bridge was tested on two separate occasions. The results of the tests were that each instrument nominally performed and collected data as expected. The data are now being overlaid and detailed comparison studies are underway, Figure IV-3.

Figure IV-1. HERMES/PERES II Ground Penetrating Radar Test of Carter Creek Bridge, Irvington, VA

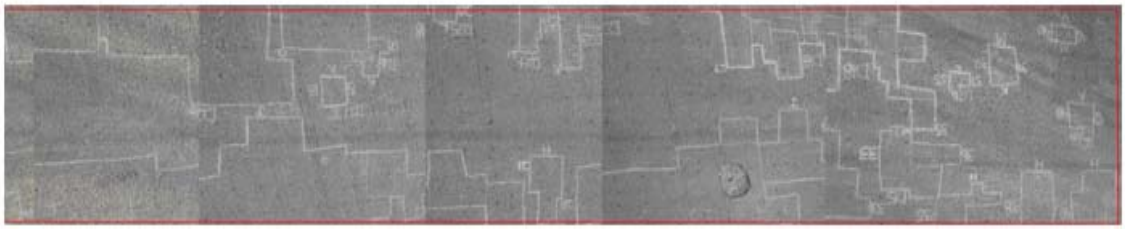

Figure IV- 2. Photographic image of Carter Creek Bridge, delaminations identified by chain drag marked with chalk

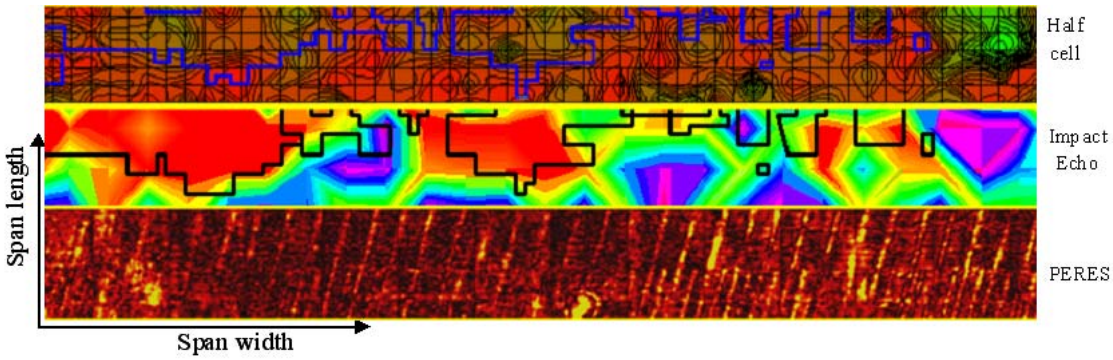

Figure IV- 3. Half cell, impact echo and HERMES/PERES II ground penetrating radar images with chain drag identified delaminations indicated for same section of Carter Creek Bridge deck

Load Testing and Analysis of Reinforced Concrete Bridges without Documentation

Many bridges constructed during the early 20th century often have limited or no documentation describing the type/layout/details of their foundation, substructure, or superstructure. This research involved four separate truck load tests (and associated analytical modeling) of two reinforced concrete bridges Figure IV-4. The tests were aimed at (1) accurately characterizing their behavior, (2) determining their safe load capacity, and (3) forecasting the estimated safe load carrying capacity into the future (based on the established salient behavior mechanisms). Prior to conducting load tests of the two selected bridges, detailed visual inspection, non-destructive testing/scanning, and material sampling and testing were performed. The results of these preliminary investigations aided in the development of several analytical models shown in Figure IV-5 which were leveraged to estimate capacity, identify potential failure modes, design efficient instrumentation plans, and ensure safety during the load tests of each bridge.

Figure IV-4. (a) Instrumentation (b) Proof Level Load Testing

Initially, diagnostic-level load tests were conducted on each bridge; however, due to the extremely small levels of response captured, the results of these tests were not capable of providing reliable information related to bridge capacity or response mechanisms. As a result, this series of tests were augmented with proof-level load tests on each bridge using similar loads to those shown in

Figure IV-4. The responses of the proof-level load test, while still remaining quite small, were of sufficient magnitude to calibrate the analytical models shown in Figure **IV-** IV-5 and forecast capacity. Based on the results of this research WVDOT removed the posting of the two test bridges.

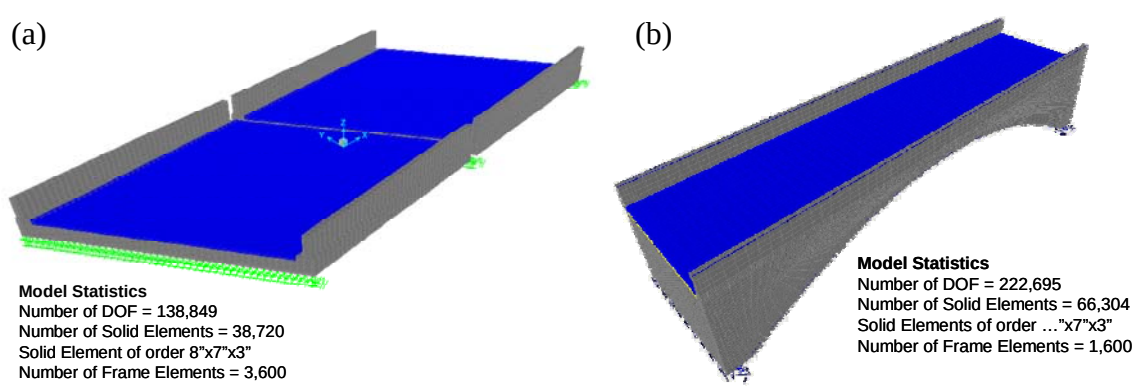

Figure IV-5. (a) Tams Slab Bridge FE Model (b) Amigo Arch Bridge FE Model

Chaos Theory Analysis and CTBR Software Development

The Advanced Research Program has supported the NDE Center to develop a new technique, Chaos Theory Analysis, in the research area of Structural Health Monitoring (SHM) of highway infrastructures. This research project included developments in advanced nonlinear dynamics analysis involving new algorithms, new data processing methods and advanced software for analysis of nonlinear bridge dynamics. An integrated bridge data analysis application software, the Chaos Theory Analysis of Bridge Response, CTBR has been developed to reveal the complex nonlinear dynamic behavior in highway bridges that may cause structural damage. This technique has significant impact in developing smart systems for long term structural health monitoring and condition assessment of the highway infrastructure.

1. Chaos Theory Analysis Technique for Structural Health Monitoring of highway infrastructure. The research consists of efforts in nonlinear dynamics analysis, stochastic dynamics analysis, nonlinear time series analysis, nonlinear finite element modeling analysis simulation and structural safety reliability analysis. The technique directly uses the monitored responses to extract the invariants of a nonlinear system to reveal structural damage and thus has significant advantages over conventional NDE/NDT techniques for real-time structural condition assessment. The research included advances in computer simulation of highway bridge structures to produce large-scale, high-fidelity, more realistic bridge dynamics. This enabled the investigation of the conditions for complex chaotic patterns in highway bridge structural responses.

2. The core methodologies in Chaos Theory Analysis as applied to Structural Health Monitoring of general highway infrastructure.

- A smart system for monitoring the structural condition of a highway bridge is shown in Figure IV-6 below. In this study, both the computer simulation and the analysis of bridge field monitoring responses are used in the chaos theory analysis for detecting structural conditions for developing smart systems.
- High-fidelity computer simulation of bridge nonlinear dynamics is performed to enable the extensive investigation of complicated conditions of the nonlinear chaotic behavior in bridge response. This involves the development of highly realistic, detailed nonlinear finite element models, Figure IV-7.
- Based on Information Topologic Theory and Geometric Dynamics, the instability of the bridge system is characterized by Lyapunov Exponents extracted from dynamics trajectories. Advanced algorithms included a Maximum Entropy (MaxEnt) method by fractal interpolation mappings (FIM) for unbiased *pdf* from nonlinear response, and a novel polynomial chaoses algorithm for extracting Lyapunov exponents, as shown in Figure IV-8.

3. Chaos Theory Analysis of Bridge Response application software for automated bridge structural health monitoring analysis. The chaos theory analysis technique involves advanced nonlinear time series analysis, nonlinear signal/data processing algorithms for damage detection, and structural health monitoring and reliability assessments of highway structures. The example figure below shows an application to structural health monitoring of highway infrastructures, Figure IV-9.

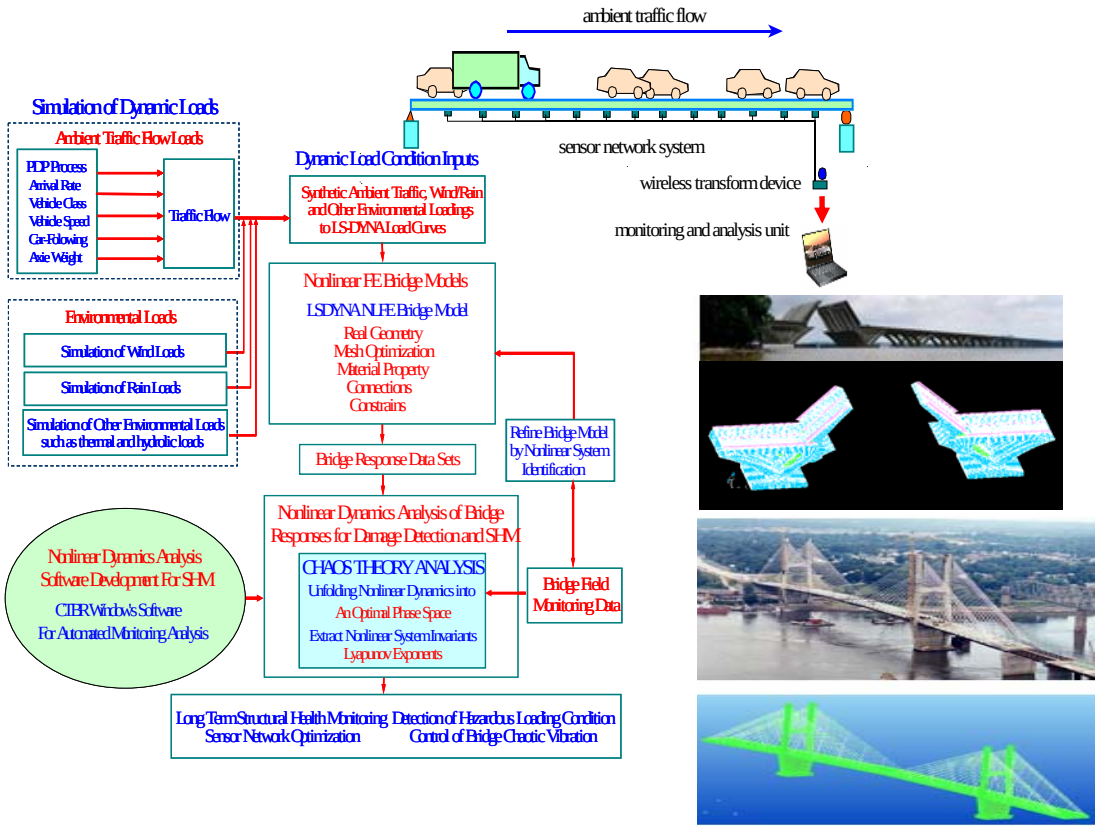

Figure IV-6. The smart system, example plots of the NLFE bridge model simulations and chaos theory analysis applied to highway bridges for a cable-stayed bridge (Bill Emerson Bridge, MO) and a bascule drawbridge (the new Woodrow Wilson Bridge at I95).

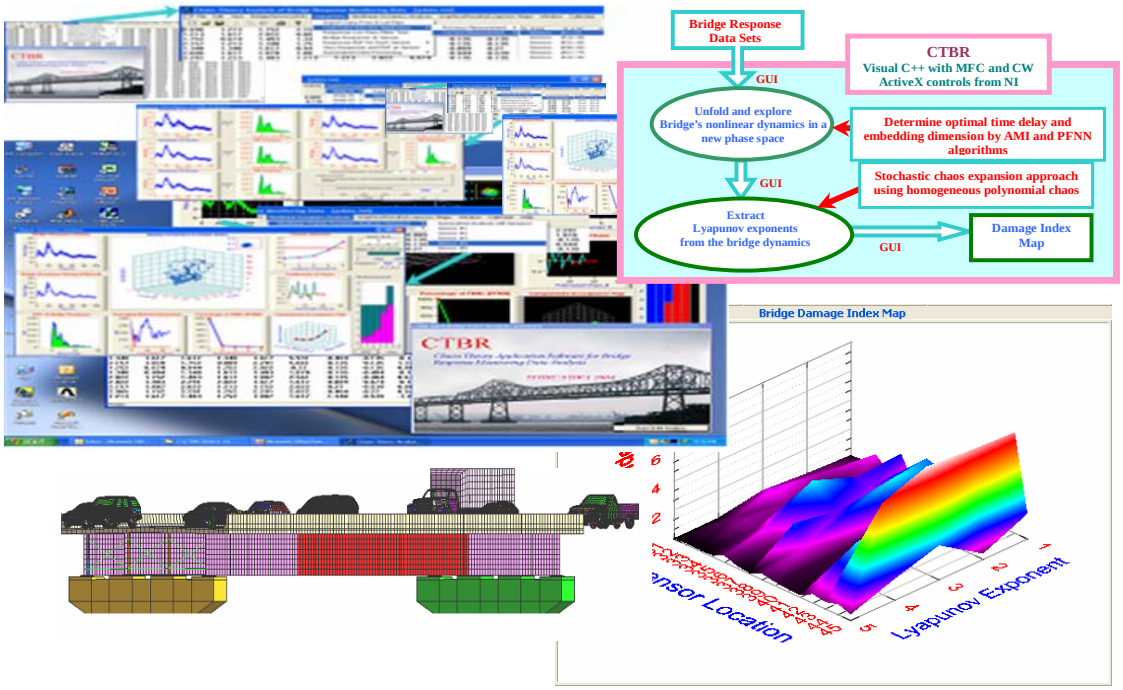

Figure IV -7. The flow chart and the screen shot of the CTBR windows software for analysis of nonlinear structural response monitoring data from highway bridges

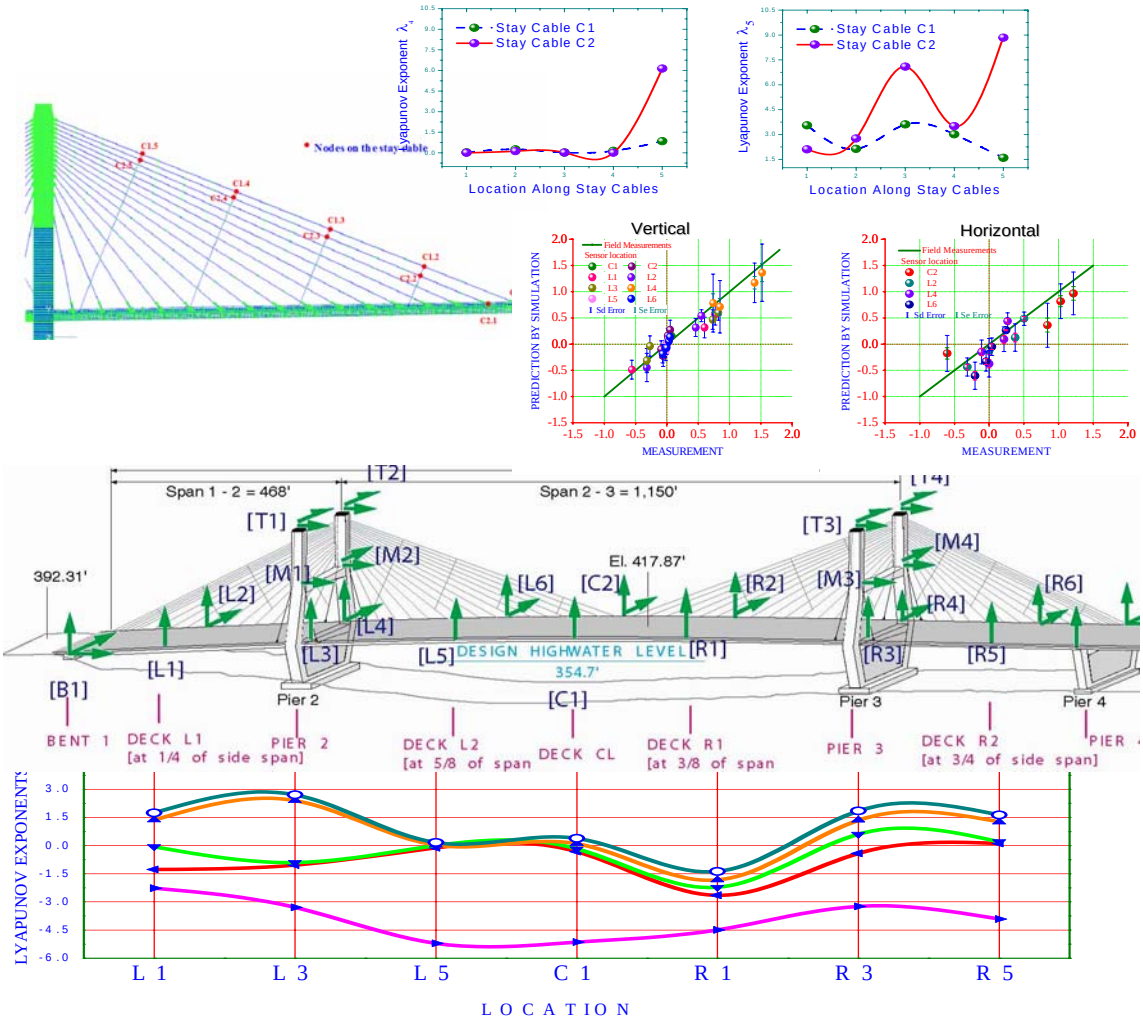

Figure IV-8. Chaotic behavior in the Bill Emerson Bridge at the locations of bridge stay cables and deck, and the normalized Lyapunov exponents from simulations vs observations from the horizontal and vertical accelerations at the bridge sensor locations serve as the base-line condition index.

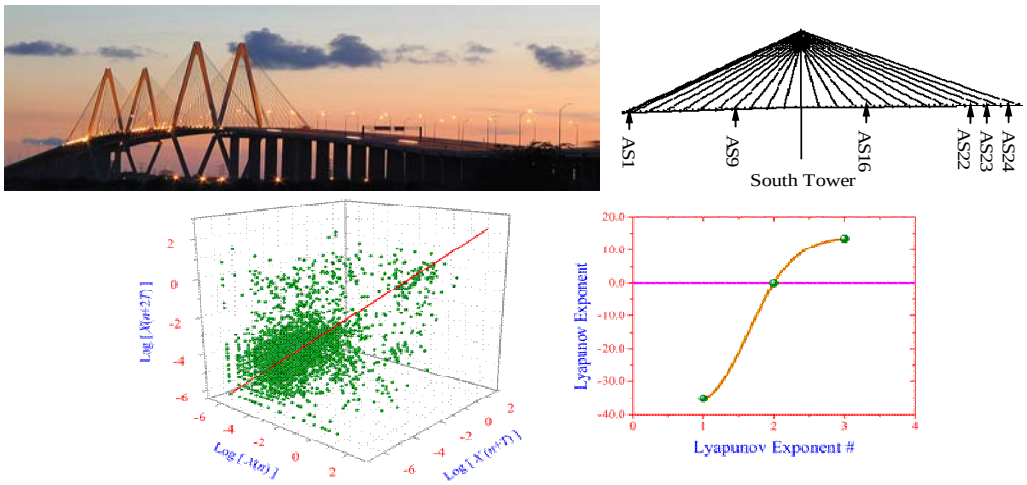

Figure IV-9. The chaos theory analysis of the wind/rain induced cable-stayed bridge vibration in Fred Hartman Bridge.

Laser Measurements on the Curved Girder Bridge

The NDE Center laser system has been used for several years to measure full-sized curved girder bridge under testing in the Structures Laboratory for the Bridge Design and Construction Team. This laser instrument can precisely measure the global movements of large structural objects and can measure very small deformation in these structural objects. Shown set up in the Structures Laboratory in Figure IV-10, has unique capabilities to make very high-resolution measurements on very large structural specimens. For example, the system was used to measure the out-of-plane distortions of the entire web of a full-sized girder under various loading configurations. Measurements were also made during erection of full-sized curved bridge girder to help characterize the optimal sequence of erection. The data collected has provided measurements that would be impossible to collect with conventional instruments. Typical data of web distortions is shown in Figure IV-11. The NDE Center laser system is unique in that it can make very high-resolution measurements over a large volume. This feature is essential for the type of structural testing on large objects that is conducted in the FHWA Structures Laboratory.

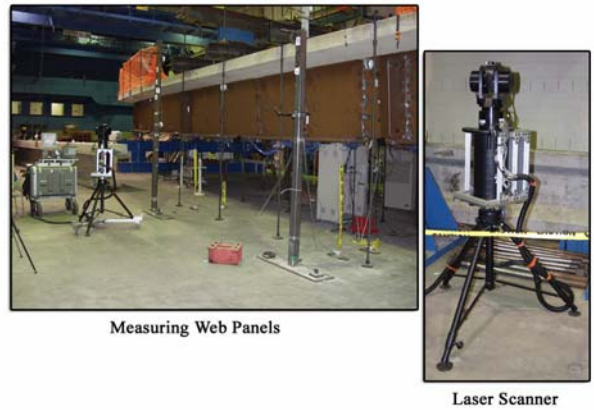

Figure IV-10. Laser System positioned on the laboratory floor for web panel measurements.

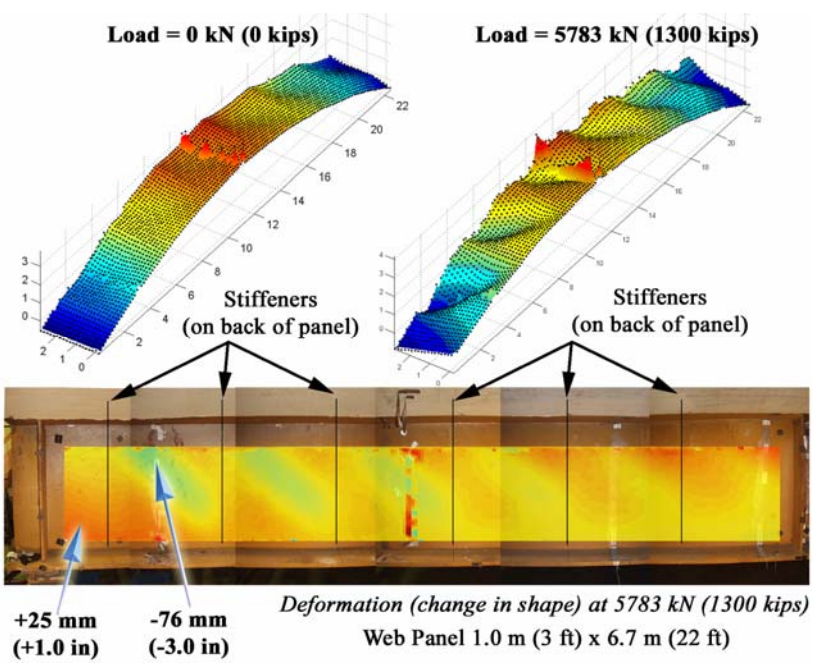

Figure IV-11. Web panel data showing distortion measurements at different load steps

Infrared Measurements on the Poplar Street Bridge

The NDE Center has developed a unique infrared (IR) thermographic system designed to inspect bridge decks in a rapid and efficient manner. The system is primarily intended for bare concrete decks and for the assessment of thin wearing surfaces on bridge decks. Recently the Missouri Department of Transportation (MoDOT) requested the use of the NDE Center IR system in order to examine the wearing surface on the Poplar Street Bridge in St. Louis, Missouri. The NDE Center IR system was used because the Poplar Street Bridge is very large and carries a significant amount of traffic. Figure IV-12 illustrates the Poplar Street Bridge and typical framing. Lane closure at this bridge site is difficult and data must be collected with minimal disruption to traffic. The NDE Center IR system collected data on the entire Poplar Street Bridge deck without requiring a lane closure. This structure has 8 lanes of traffic with a total span length of about 670 m (2200 ft). In total, over 20.1 km (12.5 miles) of data (over 37,000 m^2 (400,000 ft^2)) were collected. The NDE Center IR system was well suited to assess this type of bridge deck as this structure has a 15.9 mm (5/8 in.) thick steel orthrotropic deck with a 12.7 mm (½ in.) thick, low-modulus epoxy concrete overlay. The goal of the testing was to identify and locate potential defect areas in the wearing surface on the bridge deck.

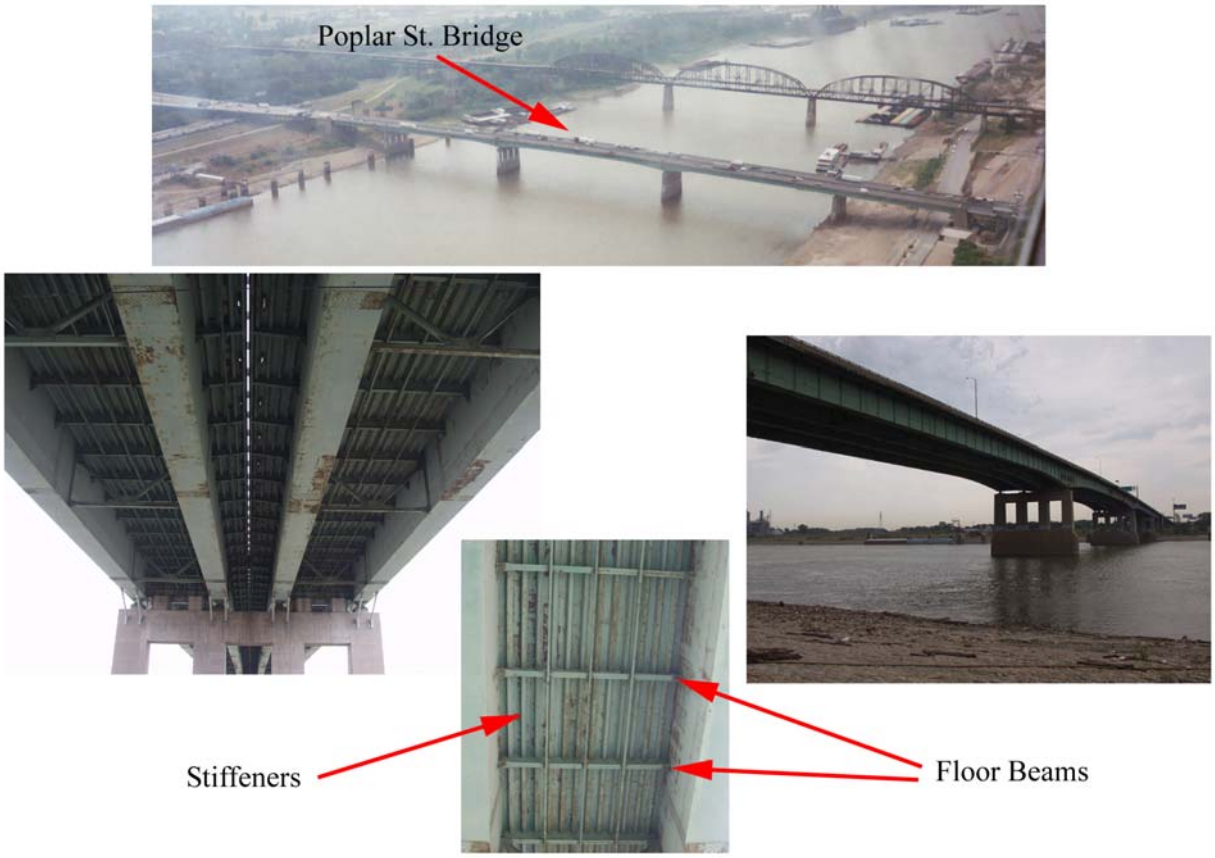

Figure IV-12. Poplar St. Bridge, St. Louis, MO.

Laser Measurements on a Maryland SHA Bridge

In April 2000 the NDE Center laser system was used to test a bridge located northeast of Baltimore, MD at the I-695 / I-95 interchange. Previous routine inspections of the structure by the Maryland State Highway Administration (MD SHA) observed that the bridge was damaged by an over height vehicle. This particular bridge is located in a high traffic area that would make repair or replacement of the damaged girder difficult and would greatly disrupt traffic flow in the vicinity. MD SHA chose to load test the bridge in order to determine if the damage was structurally significant. However, given the high traffic at the bridge site it was undesirable to close the roadway under the structure in order to setup instrumentation for a conventional load test. The NDE Center laser system provided a means to make the required measurements with minimal traffic disruption. Traffic was not altered under the test bridge. The field setup is shown in Figure IV-13. One lane and one entrance ramp on the bridge were closed for placement of the load vehicle. One lane remained open to traffic on the bridge. Because of the high traffic present at the test site, the load test was conducted at night. The NDE Center laser system was setup under the bridge in the shoulder of the roadway. In a matter of a couple of hours the system was setup and collected all test data. The deflection data collected during testing was provided to the MD SHA. All analysis of the deflection data and engineering conclusions based on the deflection was conducted by the MD SHA, which used the data to determine the structure was safe and did not require immediate repair.

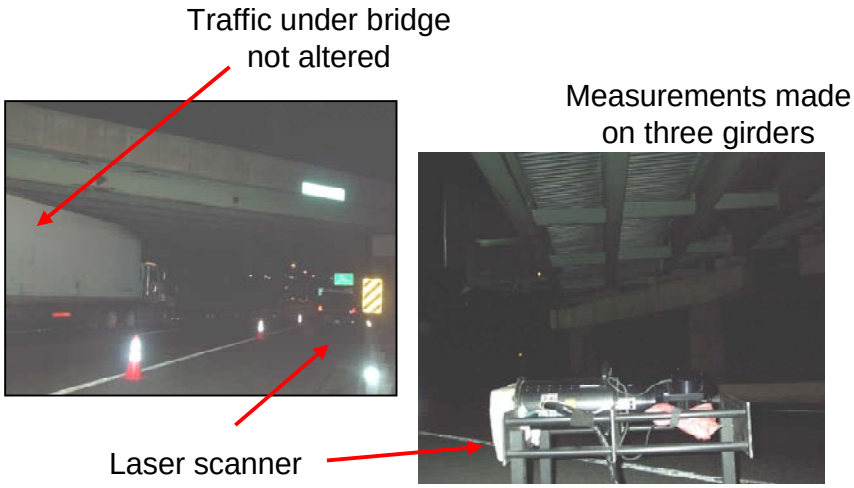

Figure IV-13. Laser System load testing a bridge near Baltimore, MD.

Literature Search on Grouting in Post Tensioning

Several failures and recent problems related to corrosion of the prestressing strands have focused new interest on performance and protection of these systems. In particular, the Ynys-y-Gwas Bridge, West Glamorgan, U.K. constructed in 1952, collapsed in 1985. This post-tensioned bridge had been inspected approximately 10 times during service with no signs of deterioration. Post collapse investigation results indicated that numerous post-tensioning strands had corroded at construction joints resulting in a very concentrated corrosion area with significant wire cross-section reduction. More corrosion related post-tensioning problems have been observed in the Sunshine Skyway and Mid-Bay Bridge in Florida.

In February 2005, FHWA conducted a literature review related to Nondestructive Evaluation Methods for Post Tensioned Highway Bridges. The purpose of the literature review was to describe typical post-tensioned bridges; summarize typical tendon configurations, existing proprietary post-tensioning systems, and existing destructive and nondestructive evaluation methods; and outline evaluation methods relative to critical inspection information.

Specific information included in the literature review is as follows.

- Bridge configuration including construction techniques and typical bridge cross sections
- Tendon elements including steel wires and strands, ducts, and grout materials
- Proprietary post-tensioning systems from VSL, DSI, and Freyssinet
- Inspection details and limitations including destructive and nondestructive testing.
- Nondestructive testing methods include visual inspection, covermeters, half cell measurements, internal environmental monitoring, fiber optic sensors, precursor transformation, acoustic sounding, acoustic emissions, infrared thermography, time of flight diffraction, electromagnetic acoustic transducers, radiography, ground penetrating radar, magnetic flux leakage, ultrasonic testing, electronic time domain reflectivity, and impact echo
- Cross referencing between critical inspection information and testing methods
- Summary of approximately 65 individual articles, papers, books, product literature, etc related to durability, corrosion, grouting, nondestructive testing method comparisons, impact echo, acoustic emissions, ground penetrating radar, and ultrasonics

Literature Review of Corrosion Protection Systems for Post Tensioning

Post-tensioning systems have been used in United States bridges for over 40 years. However, in recent years, there has been an increased awareness of potential corrosion problems in highway bridges constructed using post-tensioned systems. This interest is likely due to well publicized prestressed and post-tensioned concrete bridge failures.

The challenges related to corrosion protection of post-tensioned bridges exist on two fronts; the existing inventory of bridges must be evaluated and possibly repaired, and improved corrosion protection systems must be developed and implemented in new post-tensioned bridges. The recent problems with corrosion of post-tensioning elements have existed in both cable stay and segmental bridges. The corrosion protection systems used in these bridges were developed over many years and evolved in part from past experiences with corrosion protection systems used in suspension bridges. In addition to grout-based corrosion systems, there has been a wide range of materials and systems used over the years to protect highly stressed wire or strand elements in bridges.

In July 2004, FHWA conducted a literature review related to Corrosion Protection Systems for Post Tensioned Elements in Highway Bridges. The purpose of the literature review was to identify and compile sources of information related to a wide range of corrosion protection systems used in bridge structures. These systems have included relatively rudimentary cement and water grouts to multi-layer systems incorporating HPDE ducts and fractioned waxes. The literature review is compiled in approximate chronological order, beginning with corrosion protection systems used in wire suspension bridges and moving forward to systems currently being utilized in present day cable stay bridges.

Specific information included in the literature review is as follows.

- Corrosion protection for suspension bridges including galvanized wires, galvanized wire-wrapping systems, neoprene-hypalon wrapping systems, plastic sheet coverings, fiberglass systems, grouts, and corrosion inhibitors (red lead, linseed oil, prelube, metalcoat, vapor phase inhibitors, and paint).
- Corrosion protection for cable bands, saddles, anchorages, and suspender ropes.
- Corrosion protection for cable stay systems including galvanization, red lead paste compounds, metalcoat, painting systems incorporating zinc dust, epoxy coating, and cable protection.
- Summary of approximately 30 individual articles, papers, books, product literature, etc. related to corrosion protection systems.

Reliability of Visual Inspection

The visual inspection (VI) method is the predominant NDE technique used for bridge inspection. However, since implementation of the National Bridge Inspection Standards in 1971, a complete study of the reliability of VI for highway bridge inspection has not been undertaken. Considering that VI may have limitations that affect its reliability, this research focuses on a comprehensive study to examine the reliability of the VI method for highway bridges as it is currently practiced. The study had four specific objectives. VI is a primary component of both Routine and In-Depth Inspections and, therefore, the first two objectives were to provide overall measures of the accuracy and reliability of Routine and In-Depth Inspections. The third objective was to study the influence of several key factors to provide a qualitative measure of their influence on the reliability of Routine and In-Depth Inspections. The fourth objective was to study the differences between State inspection procedures and reports. Figure IV-14 illustrates a State Bridge Inspector on-site at one of the test bridges along with an NDE Center researcher who was monitoring the inspector's actions and processes.

Figure IV-14. Visual inspection of bridge with NDE Center observer.

Three primary activities were performed during the course of this study: 1) a literature review, 2) a survey of bridge inspection agencies, and 3) a series of performance trials utilizing State department of transportation bridge inspectors. The performance trials were conducted using 49 State bridge inspectors. These State bridge inspectors completed six Routine Inspections, two In-Depth Inspections, and two inspections following their respective State procedures (i.e., State dependent procedures). Two primary types of data were collected. The dependent data are the results of the inspections, while the independent data are the characteristics of the inspector (i.e., human factors) and the inspection environment (i.e., environmental factors). The independent data were collected through self reports, direct measurements, and firsthand observations. The methodology for the collection of this data is essential to establishing accurate cause-effect relationships with the dependent data. Figure IV-15 illustrates a State Bridge Inspector assessing conditions. Regardless of the type of inspection being completed, it was found that many inspectors did not indicate the presence of important structural aspects of the bridge that they were inspecting. From the Routine

Figure IV-15. Visual inspection of a bridge at Star facility.

Inspection tasks, it was observed that Routine Inspections were completed with significant variability. This variability was most prominent in the assignment of Condition Ratings, but was also present in inspection documentation. From the In-Depth Inspection tasks, it was observed that In-Depth Inspections were unlikely to correctly identify many of the specific types of defects for which this type of inspection was frequently prescribed. The results of this study were published in "Reliability of Visual Inspection for Highway Bridges, Volume I: Final Report," FHWA-RD-01-020, June 2001, "Reliability of Visual Inspection for Highway Bridges, Volume II: Appendices," FHWA-RD-1-021, June 2001, and "Techbrief: Reliability of Visual Inspection for Highway Bridges, Volume I: Final Report and Volume II: Appendices," FHWA-01-105, September 2001. In addition, consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at 2001 SPIE conference, 2000 TRB Annual Meeting, 2000 SMT conference.

Laboratory and Field Testing of AUT

The research has focused on the implementation of automated ultrasonic testing (AUT) and inspection techniques for quality control and quality assurance of welds during the fabrication of steel bridge structures in the fabrication shop. The AUT system used for the testing is shown in Figure IV-16. The fabrication inspection can identify internal discontinuities, determine the severity, and allow significant discontinuities to be repaired. Radiographic testing (RT) is the most common method of inspection utilized for fabrication inspection by the fabricators and bridge owners. Frequently conventional ultrasonic testing (UT) is used as a complement for the RT inspections to determine the depth of the defects identified by RT. For all fracture critical members (FCM), conventional UT together with RT is required by the Code for inspection of welds. The primary goals of research are: 1) laboratory and field testing to evaluate the effectiveness of AUT as a replacement for radiographic testing (RT) which can provide an effective quality control tool that satisfies the needs of bridge owners, and 2) to determine if the conventional UT procedures described in the Code can be applied to AUT.

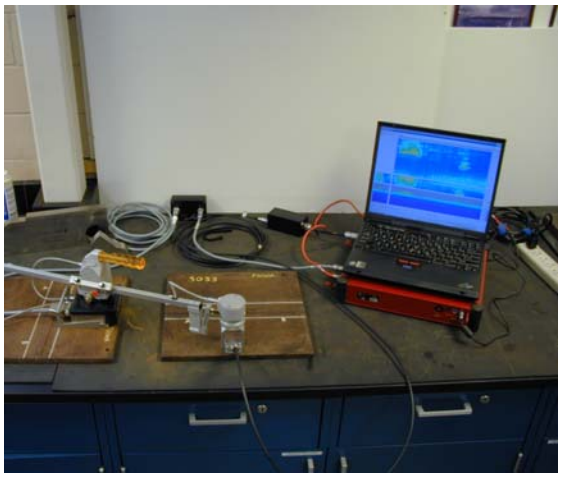

Figure IV-16. Laboratory evaluation of AUT in the NDE Center.

To achieve the research objectives, first a market survey of the available sources for AUT systems was carried out and an AUT system was purchased. Second, a laboratory testing and evaluation of the AUT was conducted on laboratory specimens with butt welds containing common weld defects. Third, a field-testing and evaluation of AUT was conducted in the fabrication shop to assess the feasibility, accuracy, reliability, and defect sensitivity of AUT relative to RT during the fabrication process. Figure IV-17 illustrates a field testing effort. The outcome of this research study revealed that images created by AUT provided similar or even more details as radiographic film created by RT. The AUT images provided evidence that a given weld had been fully inspected as the radiographic film did. The AUT images and ultrasonic signals could be retained for future reference, and the spatial location, depth, orientation, and extent of the defects could be displayed in AUT images. AUT provided significantly more information about the quality of workmanship to the bridge owner than conventional UT and RT. However, the differences in the detection of volumetric and planar defects that exist between RT and UT also exist between RT and AUT. The results of this study were published in "Laboratory and Field Testing of Automated Ultrasonic Testing (AUT) Systems for Steel Highway Bridges," FHWA-HRT-04-124, April 2005. In addition, consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at the 2006 Annual TRB Meeting, 2004 CONMAT conference, 2004 ASNT conference, 2004 SMT conference, 2003 NSBA meeting, 2003 TRB annual meeting.

Figure IV-17. Field testing of AUT in the bridge fabrication shop.

Assessment of Automated Ultrasonic Inspection

The NDE Center conducted an exploratory study focusing on the implementation of automated ultrasonic testing (AUT) methods for use in weld inspections during steel bridge fabrication. The primary goals were to document the implementation of AUT techniques in other industries including nuclear, chemical, pipeline, and aerospace, and to assess the possible use of AUT in bridge fabrication industry as compared to other industries. The study was comprised of three components. First, a search was performed to determine previous efforts to compare ultrasonic, automated ultrasonic, and radiographic inspection of welds in industries other than steel bridge fabrication. This search also included a preliminary market survey of the available sources for AUT equipment and a comparison of the Figure IV-18 illustrates the system selected for use in the study. The second portion of the study was a proof-of-concept study comparing AUT and radiographic inspection of welds containing common defects. The defects will include porosity, lack of fusion, slag inclusions, and cracking. The final portion of the study focused on developing a work plan for determining the reliability of ultrasonic inspection relative to radiographic inspection during the steel bridge fabrication process. Consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at the 2001 TRB annual meeting.

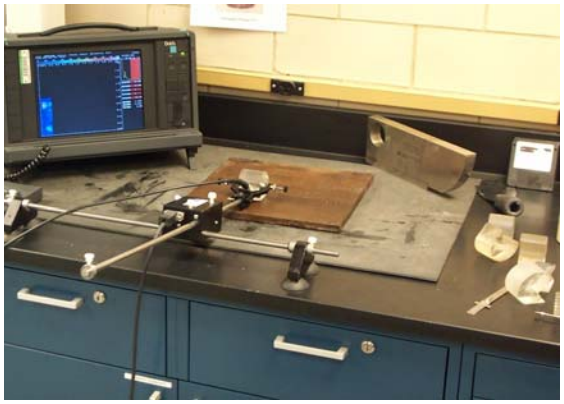

Figure IV-18. Preliminary assessment of AUT.

Evaluation of the HERMES GPR System

Bridges are critical components in the flow of traffic and the costs of closure may often be prohibitively high. Deck in a bridge is a surface where traffic flows over. To address the need for quantitative information on the condition of concrete bridge decks the FHWA is pursuing a program of research and development of non-destructive evaluation methods. One aspect of this work is the investigation of bridge deck integrity. The development of advanced ground-penetrating radar (GPR) systems for the inspection of bridge decks was initiated by the NDE Center. The objective of this research program was to build a GPR system that surveys the condition of concrete deck at the normal highway speed without disrupting traffic flow.

Figure IV-19. HERMES bridge inspector surveying bridge deck at highway speed.

Two radar systems had been designed and built by Lawrence Livermore National Laboratory under HERMES research program. The HERMES bridge inspector (High-speed Electromagnetic Roadway Mapping and Evaluation System) was designed to survey the deck condition during normal traffic flow. This system is shown in Figure IV-19. Surveys at a variety of traffic speeds had been conducted. This system was based around a 64 channel antenna array covering 1.9 m in width with a sampling density of 3 cm. To investigate specific areas of a bridge deck that require detailed inspection, a slower cart mounted radar has been produced. This system is named PERES (Precision Electromagnetic Roadway Evaluation System). This system is shown in Figure IV-20. The density of data coverage with PERES is 1 cm and an average of 100 samples is taken at each location to improve the signal to noise ratio. The results of this study were published in "Phenomenology Study of HERMES Ground Penetrating Radar Technology for Detection and Identification of Common Bridge Deck Features," FHWA-RD-01-090, June 2001; "Testing and Evaluation of the HERMES Bridge Inspector," DTFH61-C-98-00050, January 2000. In addition, consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at the 2001 Proceedings of Structural Faults and Repair, England, 2001 TRB annual meeting, 2001 ASCE, 2001 ACI, 2000 Materials Evaluation, 2000 SMT conference 2000 ACI proceedings, 2000 ASNT, 2000 Geophysics Journal.

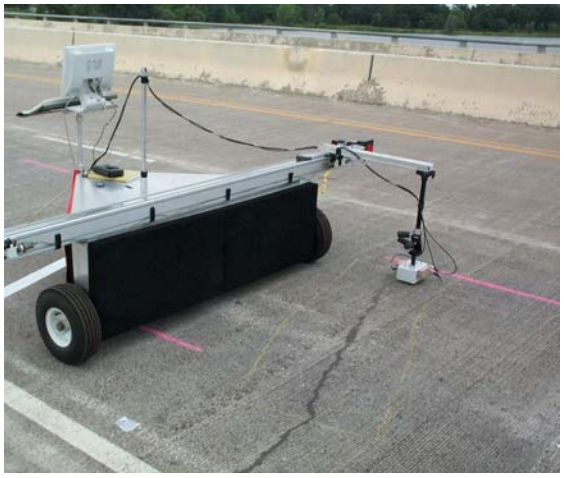

Figure IV-20. PERES bridge inspector performing detailed inspection of bridge deck.

Evaluation of the PERES II Bridge Inspector System

The PERES II, Precision Electromagnetic Roadway Evaluation System, project was initiated to develop new ground penetrating radar (GPR) technology for bridge deck evaluation. The original HERMES/PERES project addressed a broad range of technical challenges that evolved from several important goals. The primary goal of the original HERMES/PERES project was to detect delaminations in concrete bridge decks using GPR technology, but additional goals included collecting data at high speeds (up to highway speeds) and developing data visualization and analysis techniques to make GPR data easier to interpret effectively. PERES II, a second generation prototype GPR system, has been developed to address technical issues from the original HERMES/PERES project and to achieve

Figure IV-21. PERES-II bridge inspector imaging a concrete bridge deck.

new performance objectives specified by the NDE Center and the sponsoring State Department of Transportations. The PERES-II system is shown in Figure IV-21. Lawrence Livermore National Laboratory was tasked with designing and building PERES II. Three specific goals were set for PERES II project that included the prototype performance requirements: 1) to detect defects, at elevations from the top reinforcing steel mat to the deck mid-section, with a reliability of 90% through asphalt and concrete overlays, 2) to image delaminations in a bridge with a concrete or asphalt overlay with a spatial accuracy equal to the accuracy of the chain drag method applied on a bare concrete deck, 3) to detect defects at the elevation of the bottom reinforcing steel mat. The NDE Center conducted a field and laboratory test program that reflected these goals as closely as possible. The results of this study were published in "Phenomenology Study of HERMES Ground Penetrating Radar Technology for Detection and Identification of Common Bridge Deck Features," Publication No. FHWA-RD-01-090, June 2001; "Testing and Evaluation of the HERMES Bridge Inspector," Publication No. DTFH61-C-98-00050, January 2000. In addition, consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at the 2001 Proceedings of Structural Faults and Repair, England; 2000 Materials Evaluation.

Detection of FRP Debonding Characteristics with Infrared Thermography

The use of fiber-reinforced polymer (FRP) composite materials to repair or retrofit various civil structures is becoming popular. IR instrumentation provides a good tool for accessing the quality of a composite repair and to monitor the condition of the repair over time. Several handheld IR cameras are manufactured that are easy to use for this application. Typical use of an IR camera is shown in Figure IV-22. For this research study, the deteriorated prestressed concrete box girder beams that were repaired and retrofitted by FRP laminates to strengthen the load carrying capacity were used. IR technology was used to evaluate the quality of bond between the FRP and beam after installation of FRP. In addition, IR technology was used to determine the debonding of FRP during loading. The NDE Center provides technical assistance to state DOTs or other agencies that need assistance in the use or requirements of instrumentation for IR inspection of composites.

Figure IV-22. IR inspection to detection debonding of FRP laminate and concrete girder.

Guidelines for Ultrasonic Inspection of Hanger Pins

Bridge pin and hanger assemblies are categorized as fracture critical member (FCM). The failure of assembly may result in partial or complete collapse of the bridge structure. The hanger-pin assembly is not usually prone to development of fatigue cracks. A typical hanger pin inspection effort is shown in Figure IV-23. However, the assembly experiences unusual stress when the pin froze up due to environmental conditions. These events reduce the assembly's fatigue life leading to the pin or hanger cracking. The objective of this research work is to develop a document describing the fundamentals of ultrasonic hanger pin inspection that can be used by State transportation agencies that are either inspecting pins themselves or contracting for inspection services. In addition, a limited experimental program is utilized emphasize, and more completely explain, some important aspects of ultrasonic pin inspection.

Figure IV-23. Ultrasonic testing of hanger pin.

The results of this study were published in "Guidelines for Ultrasonic Inspection of Hanger Pins," FHWA-HRT-04-042, July 2004. In addition, consistent with the technology transfer objectives for the NDE Center, technical papers and presentations reporting on this study were presented at the 2006 Annual TRB Meeting, conference,

Feasibility of Strengthening Concrete Beams Using Bonded FRP Laminate

This research focused on evaluating the effectiveness of FRP composite laminate repairs on deteriorated prestressed concrete box girder beams for increasing the load capacity. The NDE Center in collaboration with New York State DOT (NYSDOT) conducted this study. A typical test setup is shown in Figure IV-24. The objectives of the project were: 1) to investigate the actual load carrying capacity of the deteriorated box girders at the AASHTO service load level and the ultimate load level, and test the accuracy of models developed by NYSDOT and NDE Center, 2) to evaluate the effectiveness of FRP laminates on the service load and ultimate load capacity improvement of the repaired and retrofitted girder by FRP, 3) to evaluate the quality of bond between FRP and beam after installation of FRP and during loading by existing NDE technologies, 4) to develop design and construction guidelines for using FRP laminates to strengthen prestressed concrete box beams, whether for rehabilitation or rating improvement. This research ultimately helps in reducing the number of prestressed concrete bridges rated as structurally deficient, consistent with the strategic goals of the FHWA.

Figure IV-24. Load testing of deteriorated concrete box girder that is repaired and strengthened by FRP laminate.

Research Results

Publications

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Conference and Journal Publications

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Technology Transfer

Workshops

The NDE Center sponsors many workshops including at TRB annual meetings:

- Introduction to Nondestructive Evaluation Technologies for Bridges in 2002
- Condition Assessment of Cable-supported Bridges: Inspection of Suspension Cables, Stay-Cables, Post-tensioning Tendons and Pre-stressing Strand in 2006.

TRB Sessions

The NDE Center sponsors annually several TRB sessions on research and technology related to the NDE of infrastructure and structural health monitoring.

TRB NDE Subcommittee

The NDE Center sponsors annually subcommittee meeting titled “Non-destructive Evaluation (NDE) of Structures - AFF40 (1).”

Structural Materials Technology (SMT) Conference

The NDE Center sponsors the SMT Conference held biannually.

ASNT Research Symposium

The NDE Center participates in the ASNT research symposium.

Conference Sessions

The NDE Center organizes many NDE and SHM sessions at international conferences.

Customers and Stakeholders

Customers and Stakeholders Engagement in the Research

Customers and Stakeholders frequently define the nature of the research and in many cases actually develop the scope of work for the research plan. In other cases the stakeholders simply request data and information for their presentations or publications. Depending upon the task and research, the stakeholder may work through the Federal Technical Manager to interact with laboratory research or in other cases where the customer directly sponsors the research communications may be directly between the technical sponsor and laboratory staff.

Communications during the research is often in the form of emails and weekly and/or monthly presentations on the progress and developments in the research as well as review of issues or challenges that may have been discovered. Interim and final reports are used to document and provide research plan and findings to conclude research for stakeholders.

The primary stakeholder and customers in the laboratory activities are the FHWA and State DOT infrastructure engineers who specify or test materials on structure. The following sections provide a list of stakeholders and customers who are internal to FHWA and those at DOT's associations, academic or other institutions that may use the information provided by the NDE laboratory.

Customers and Stakeholders

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Customers and Stakeholders

State and Federal Collaborations

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* Participating as a NDE Laboratory Assessment Review Panel Member

Success Stories

FHWA NDE Center

Bridge Deck Delaminations Detection
A series of studies conducted at the FHWA's NDE Center has demonstrated the ability of infrared thermography (IR) to detect delaminations in bridge decks. A vehicle-mounted, dual-band infrared system has been tested under both laboratory and field conditions and shown to be able to detect shallow delaminations in concrete bridge decks. The IR system being used for this study includes both short and long wave infrared and has been combined with a visual image camera to capture surface conditions of the bridge deck. Continuing studies are focused on additional tests to assess the systems capability under varying field conditions.

Chaos Theory Analysis of Bridge Response Monitoring Data
The FHWA's NDE Center is continuing a significant research effort related to Chaos Theory Analysis of Bridge Response Monitoring Data (CTBR) analysis software for Bridge Structural Health Monitoring. As part of this work, the fractal interpolation algorithm has been incorporated into the CTBR software to improve the PDF (probability density function) computation from monitored bridge chaotic response data. The work includes enhancements to the analysis, graphics and input/output functions of the CTBR software. Development of a User's Guide and analysis of data sets from bridge health monitoring systems are part of the continuing work.

Automated Ultrasonic Testing Systems
The assessment of currently available Automated Ultrasonic Testing Systems (AUT) has been completed at the FHWA's NDE Center. In this study, the reliability of the AUT system to detect flaws in butt welds used in steel girder bridges was shown to be comparable to currently used radiographic equipment. Reduced health hazards and positive documentation of the inspection process are significant advances associated with AUT systems. On-going studies are focused on the ability of AUT systems to detect defects in welds in other configurations including T-joints.

Detecting Voids in Grout in Post Tensioned Concrete
Reliable NDE methods and techniques to detect voids in grout in post tensioned concrete bridges are needed for better assessments of existing conditions. Through the FHWA's NDE Center, a comprehensive review of available NDE tools has been made to identify potential techniques for detection of voids in grouted tendons. The results of this effort are aimed at identifying NDE systems that can detect voids in various tendon profiles and other as-built conditions. NDE systems identified to have high potentials for reliable defect detection will be recommended for more in-depth assessment.

Infrared Thermography on Poplar Street Bridge

The NDE Center Infrared (IR) system was very successful in finding delaminations in the polymer concrete overlay on the Poplar Street Bridge in St. Louis. This multi-span steel box girder bridge has an orthotropic steel plate deck where the deck acts as the top flange of the box girders and is also the riding surface. This design makes for a very light structure but also makes maintenance of the riding surface with an AADT of 100,000 very difficult. A nominal ½ inch overlay was placed on top of its 5/8 inch steel plate deck in 1992. At each end, elevations with expansion joints were matched by wedging ½ inch layers up to a 1 ½ inch thickness. It was hoped that because of the low modulus of the Transpo T-48 overlay that the thick wedge would not cause any brittle failures in the material over several cold winters. Another concern was stresses caused by the welds of the longitudinal stiffeners and the transverse floor beam connections to the bottom of the deck plate might cause excessive cracking of the overlay in these areas. In 1999 patches totaling less than 4% of the deck area were done. The patches still remained in good shape but Missouri and Illinois were looking at a 2007 project to replace the entire overlay. In August 2003 the NDE Center infrared system was very successful in determining how much patching would be needed to last until the new overlay. Figure 1 illustrates the identification of areas where debonding has occurred. The system was used to measure the bridge deck without requiring any lane closures. A detailed report documented suspected defect areas was written and provided to MODOT. The NDE Center IR system provided data to MODOT that was not available by any other means and aided in the efficient use of funds for rehabilitation of one of their structures.

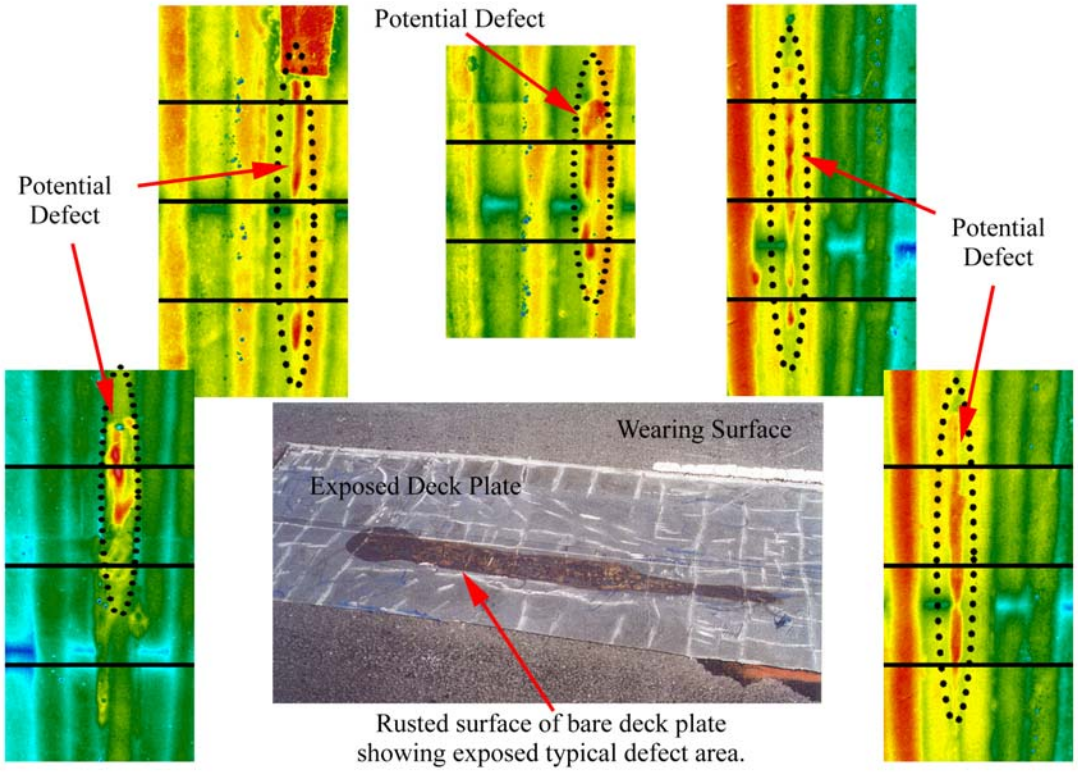


Figure 1. Typical IR Images of Potential Defects

The Advanced Research Program at TFHRC
Has been supported by the NDE Center in efforts to develop a new technique, Chaos Theory Analysis, in the research area of Structural Health Monitoring (SHM) of highway infrastructures. This research project included developments in advanced nonlinear dynamics analysis involving new algorithms, new data processing methods and advanced software for analysis of nonlinear bridge dynamics. An integrated bridge data analysis application software, the CTBR (Chaos Theory Analysis of Bridge Response), has been developed for performing the core task of bridge structural health monitoring analysis to reveal and analyze the irregular and complex nonlinear dynamics behavior in highway bridges that may causes structural damages. Recent applications based on both field data and computer simulations have illustrated that this chaos theory analysis technique has significant impacts in developing advanced smart systems for long term structural health monitoring and condition assessment of highway infrastructures.

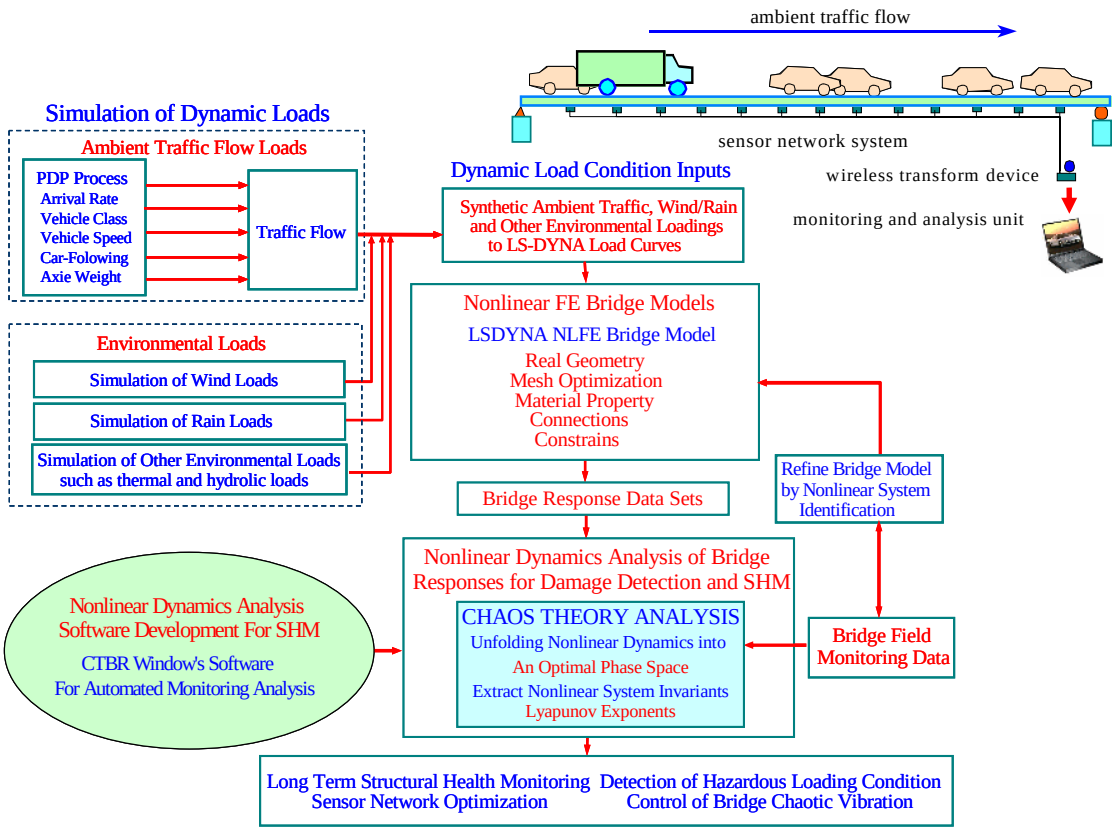
1. Chaos theory analysis technique for structural health monitoring (SHM) of highway infrastructures. The research in developing the Chaos Theory Analysis technique for highway infrastructure SHM consists of a multi-discipline research effort involving nonlinear structural dynamics analysis, stochastic dynamics analysis, nonlinear time series analysis, nonlinear finite element modeling/analysis/simulation and structural safety and reliability analysis. The analysis technique concerns the structure's nonlinear, irregular behavior that causes structural damage in highway bridges and directly uses the monitored structural responses to extract the invariants of a general nonlinear system to sensitively reveal both local and regional property changes in a system caused by structural damage. This technique has significant advantages over most conventional NDE/NDT techniques, since the later are often limited for real-time structural condition assessment due to complex material properties, environmental and loading conditions in general highway infrastructures.

The research included significant advances in the nonlinear finite element modeling and computer simulation of highway bridge structures to produce large-scale, high-fidelity, more realistic bridge dynamics in order to reveal the hidden mechanisms that are critical for causing structural damages. This enabled the investigation of the loading and structural conditions that give rise to complex chaotic patterns structural response in highway bridges when subjected to combined traffic flow and wind/rain load excitations. The analysis technique based on using chaos parameters is shown important for determining the sensitivity of structural health monitoring systems to detect various types of damages in highway bridge structures.

The area of research concerns has focused on the development of new algorithms in analysis of nonlinear structural response data for nonlinear and chaotic behaviors. These included a new method using the fractal interpolating mapping (FIM) based on an iterated function system (IFS) in Maximum Entropy evaluations to achieve accurate estimation of the probability density functions (PDF) from nonlinear highway bridge responses and an advanced polynomial chaoses algorithm for non-Gaussian random variables in capturing the chaotic trajectories in the bridge structural dynamics to extract nonlinear system invariants. The research also concerned the development of a user-friendly Windows-based software, the CTBR, Chaos Theory Analysis of Bridge Response, for analysis of highway bridge conditions.

2. The concepts and core methodologies in chaos theory analysis applied to structural health monitoring (SHM) of general highway infrastructures.

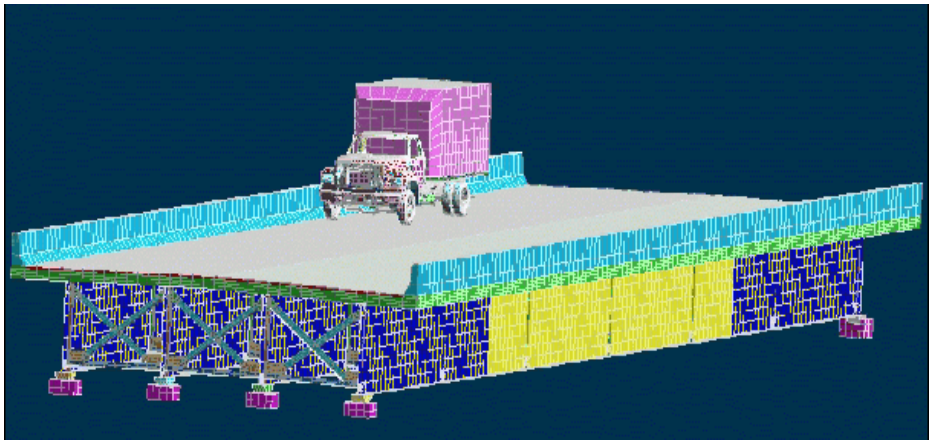
- Smart systems for damage detection and structural health monitoring (SHM) of highway bridge structures. A smart structure system for monitoring the structural condition of a highway bridge is shown in the figure below, in which the multi-channel dynamic responses of the bridge structure were collected by networked sensors and a wireless device sends the information to a remote mobile unit for analysis about the bridge conditions. In this study, the research is performed to produce high-fidelity computer simulations of bridge nonlinear dynamics to enable the extensive investigation of complicated conditions of the nonlinear chaotic behavior in bridge response. Both the computer simulation of nonlinear finite element bridge models and the analysis of actual bridge field monitoring responses are used in the development of chaos theory analysis techniques for detecting structural conditions useful in developing smart structure systems. The chart flow in Figure.1 shows such a process.



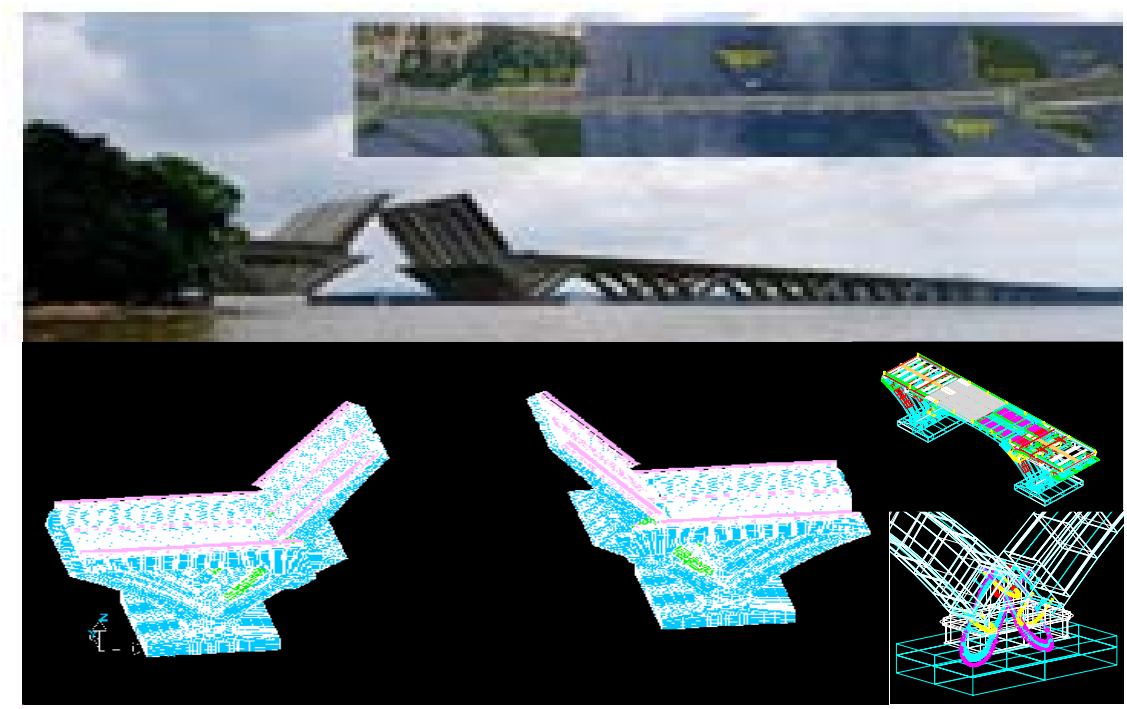
The smart system, NLFE bridge model simulation and chaos theory analysis applied to highway bridges

- Nonlinear finite element bridge model development. This involves the development of highly realistic, detailed nonlinear finite element models for several typical highway bridge structures and using advanced nonlinear dynamics analysis software for extensive, high fidelity computer simulation and analysis of the bridge nonlinear dynamics. The nonlinear 3-dimensional finite element software LS-DYNA has been used to simulate actual bridge response of increasing complexity. Several key features have been addressed in modeling these typical bridge structures. These include: realistic component geometry, material constitutive model,

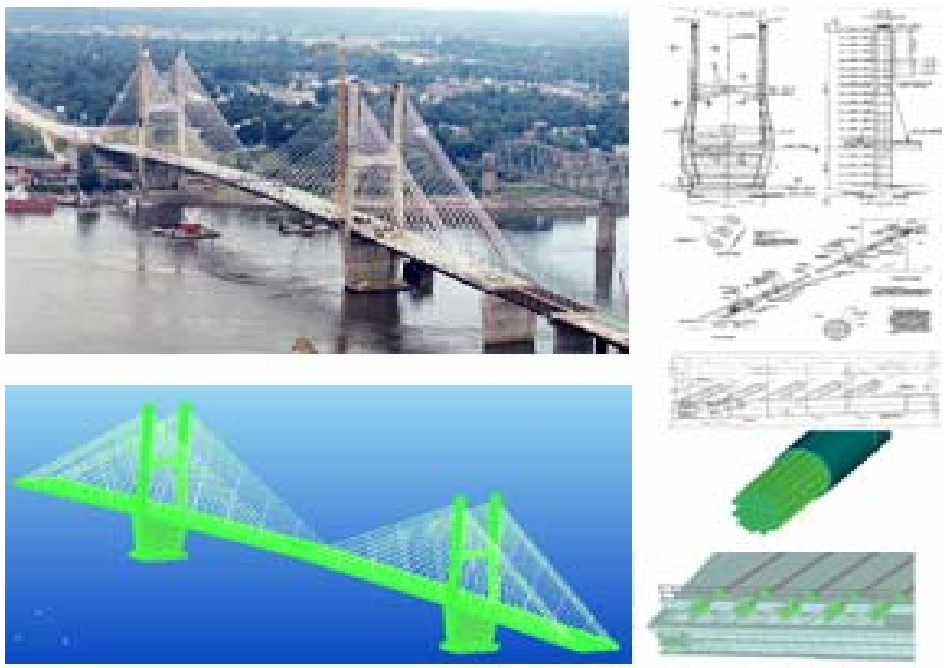
structural boundary conditions/connections and dynamical loads involved in simulation. The figures below show some sample plots of these nonlinear finite element bridge models.



Nonlinear finite element bridge models for the most popular AASHTO standard steel girder bridge

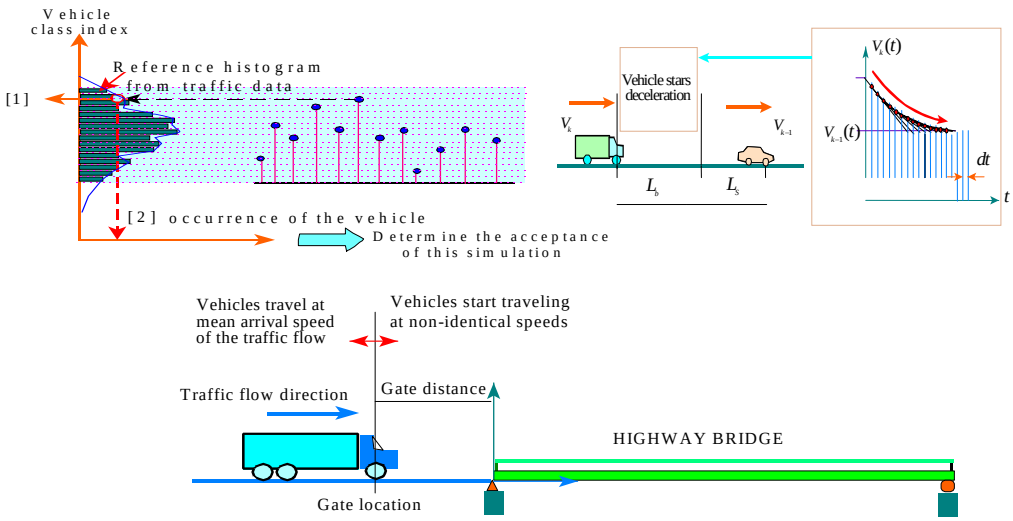


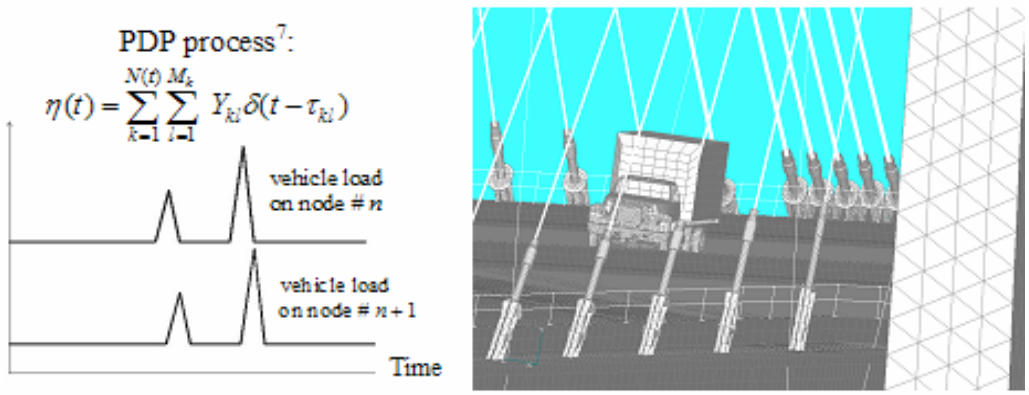
Nonlinear finite element bridge models for a bascule drawbridge (the new Woodrow Wilson Bridge at I95).



Nonlinear finite element bridge model for a cable-stayed bridge (Bill Emerson Memorial Bridge. MO)

- Special attention is placed in the simulation of the dynamic loads in nonlinear dynamics analysis. The numerical simulations of the traffic flow loads to the bridge structures considered the form of ambient traffic loadings. The dynamic loads to highway bridges due to multi-lane ambient traffic flows with varying arrival rates are described by the Poisson Distributed Pulse (PDP) process as shown below:





Simulation of the PDP ambient traffic flow loads of varying arrival rate

- Advanced study of the complex nonlinear dynamics behavior has been performed, based on both the nonlinear finite element bridge model simulation and the analysis of filed structural health monitoring data sets, to reveal the previously unknown, complex nonlinear or chaotic behavior in general highway bridges.

- Concepts of chaos theory analysis. Modern chaotic dynamics is developed based on embedding theory, information/topologic theory and geometric dynamics analysis. In particular, the dynamics of a deterministic nonlinear system is analyzed in a phase space. In this phase space, the time is implicit and the dynamics appear as orbits around the equilibrium point or attractor of the nonlinear system. The instability or chaotic behavior of the system is characterized by a set of nonlinear system invariants, the Lyapunov Exponents, extracted from the trajectories. A positive Lyapunov exponent indicates the existence of diverging component of motion and/or chaotic behavior, the causes of structural damage. Thus, the key step involved in the chaos theory analysis requires to unfold the monitored structural response into the phase space and then to extract these nonlinear system invariants. Several advanced algorithms are developed in this research for reliable and accurate evaluation of the system's nonlinear behavior.

- Enhanced Maximum Entropy (MaxEnt) PDF estimation from nonlinear response. Accurate estimation of the unbiased probability density function (PDF) from bridge response data has particular importance in analyses of the nonlinear dynamics behavior. The maximum entropy approach determines the most unbiased PDF estimation

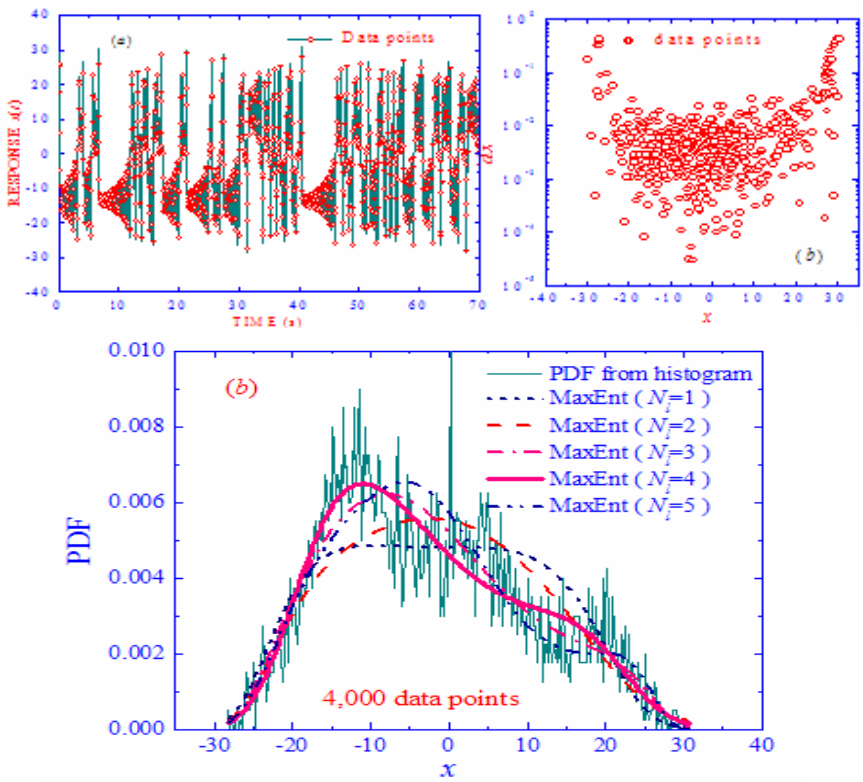
$$p(x) = \exp\left(-\lambda_0 - \sum_{i=1}^{r} \lambda_i g_i(x)\right) \qquad (2)$$

under specified statistical constraints that maximizes the entropy:

$$S = -\int_{\omega} p(x) \ln[p(x)]\, dx \qquad (3)$$

This study used an advanced fractal interpolation mapping scheme based on an iterated function system (IFS) in the entropy computations to achieve significantly improved maximum entropy PDF estimation. The figures below show the sample plot that significantly improved PDF is

achieved for the nonlinear response distribution from a typical nonlinear chaotic system, the Lorenz system.



Nonlinear dynamics response, data variation and the improved MaxEnt PDF distributions

- New algorithms for nonlinear dynamics analysis. The above enhanced Maximum Entropy PDF estimation approach is used in the chaos theory analysis to achieve the most unbiased probability density functions from the bridge response data. The Average Mutual Information (AMI) and the Percentage of False Nearest Neighbors (PFNN) algorithms are used to determine the optimal time delay and embedding dimension for unfolding the nonlinear dynamics. In addition, this research also developed an advanced stochastic analysis algorithm based on the random filed polynomial chaoses for extracting the Lyapunov exponents. In particular, under a random field definition, the nonlinear dynamics can be populated by

$$\mathbf{Y}(n+1) = \mathbf{F}[\mathbf{Y}(n)] = \sum_{l=1}^{L} \boldsymbol{\gamma}_l(\mathbf{Y})\, \psi_l[\mathbf{Y}(n)] \qquad (8)$$

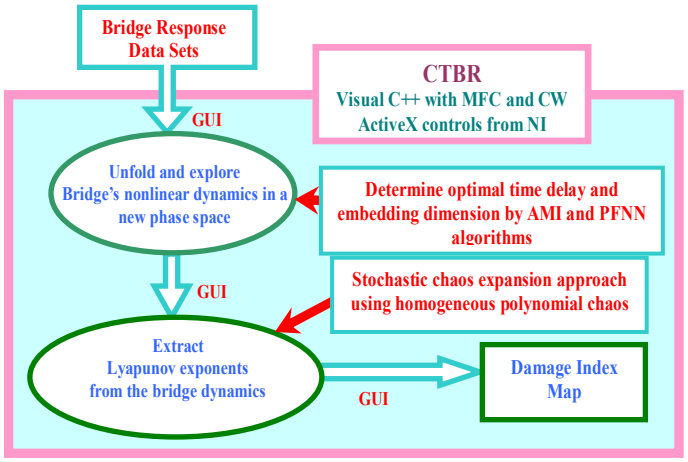
where $\psi_l[\mathbf{Y}(n)]$ $(l = 1,\ldots,L)$ are the orthogonal polynomial chaoses. Since the coefficient vector is shown to be $\boldsymbol{\gamma}_l(\mathbf{Y}) = 1/N \sum_{k=1}^{N} \mathbf{Y}(k+1)\psi_l[\mathbf{Y}(k)]$, the *Oseledec* matrix for extracting the Lyapunov exponents can be formed by the combinations of response statistics as:

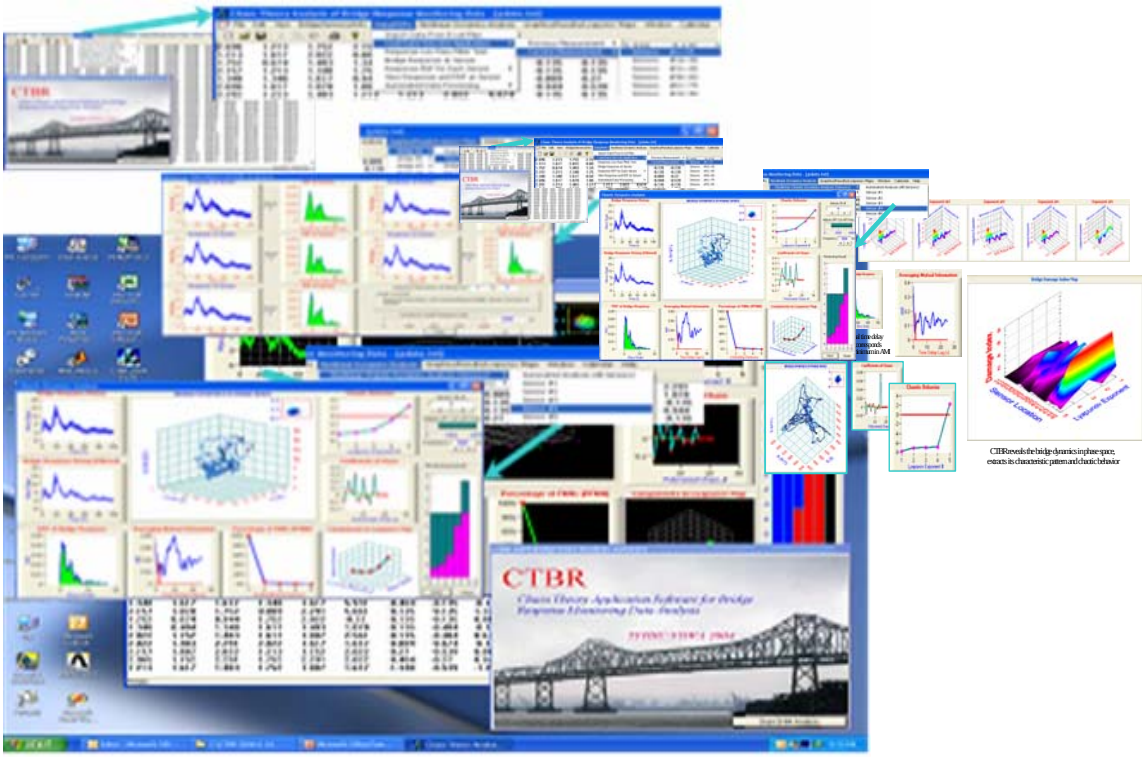
$$\mathbf{OSL}(\mathbf{Y}) = [D\bar{\mathbf{F}}(\mathbf{Y})^T D\bar{\mathbf{F}}(\mathbf{Y})]^{1/2} \qquad (10)$$

in which the components of the *Jacobian* matrix $D\bar{\mathbf{F}}(\mathbf{Y})$ can be computed by

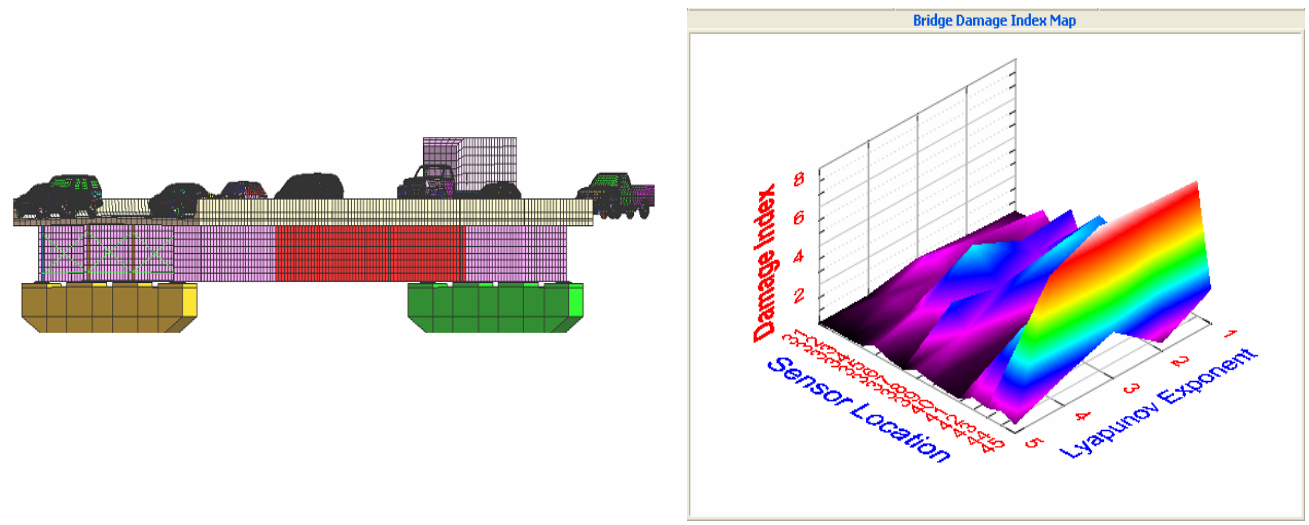
$$D\bar{F}(\mathbf{Y})_{ab} = \frac{1}{N}\sum_{l=1}^{L} \gamma_l(\mathbf{Y})_a \frac{\partial \psi_l[\mathbf{Y}(n)]_a}{\partial y_b} \qquad (11)$$

- CTBR (Chaos Theory Analysis of Bridge Response) application software for automated highway bridge structural health monitoring analysis. The development of the chaos theory analysis technique involves advanced nonlinear time series analysis, nonlinear signal/data processing algorithms for damage detection, structural unsteady conditions, structural safety, health monitoring and reliability assessments of highway structures. These advanced algorithms were implemented in the windows software CTBR for bridge structural health monitoring analysis. The example figures bellow show some applications of the CTBR software in structural health monitoring analysis of highway bridge structures.



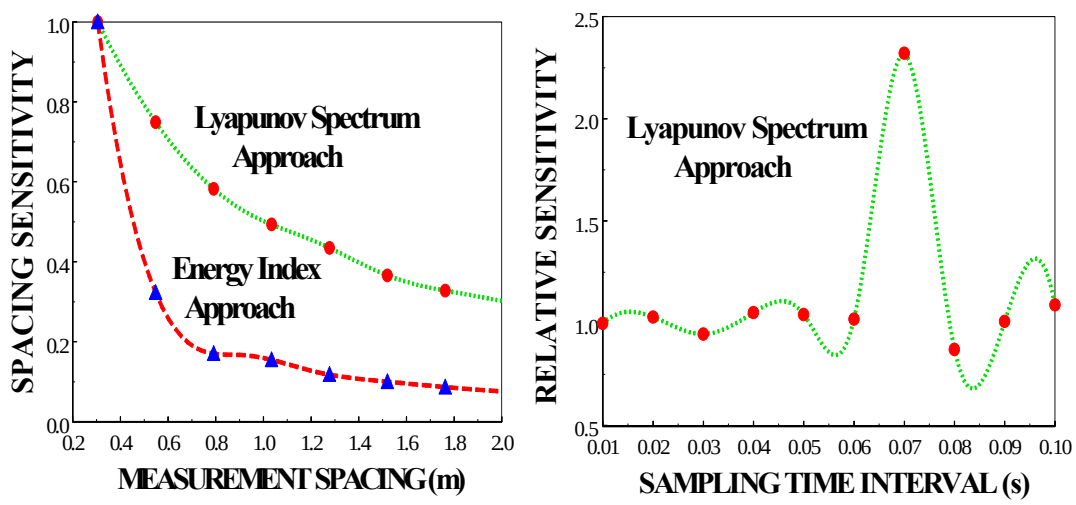


The flow chart and the screen shot of the CTBR windows software for analysis of nonlinear structural response monitoring data from highway bridges



The CTBR extracts the characteristic pattern of chaotic behavior from bridge nonlinear dynamics and detects the location of a damage in bridge girders

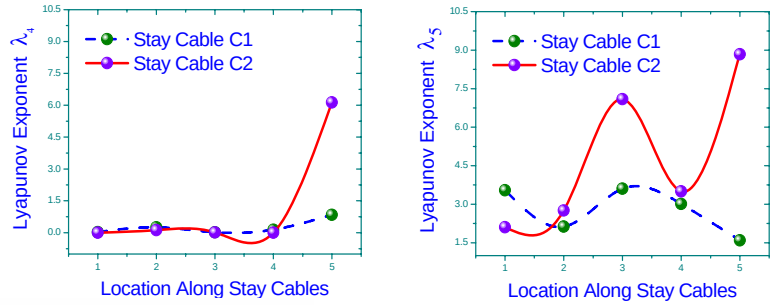
- Computational structural mechanics assessment for evaluation of large-scale sensor network design and algorithms for structural health monitoring of highway infrastructures. A sensitivity analysis of different sensor spacings and sampling time intervals was carried out. The results presented in the figure below shows the advantages of the chaos theory analysis approach relative to those obtained from the conventional energy index method.

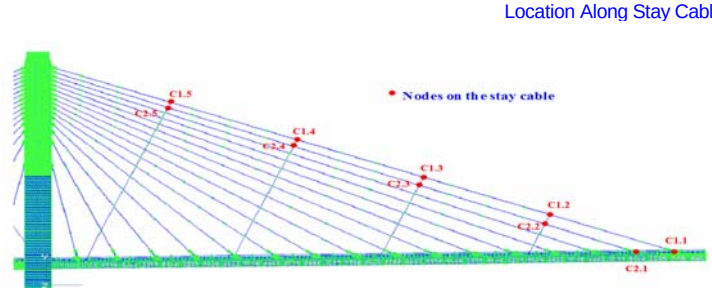


Sensitivities of the chaos theory analysis using the Lyapunov exponent spectra to measurement spacing and data sampling time.

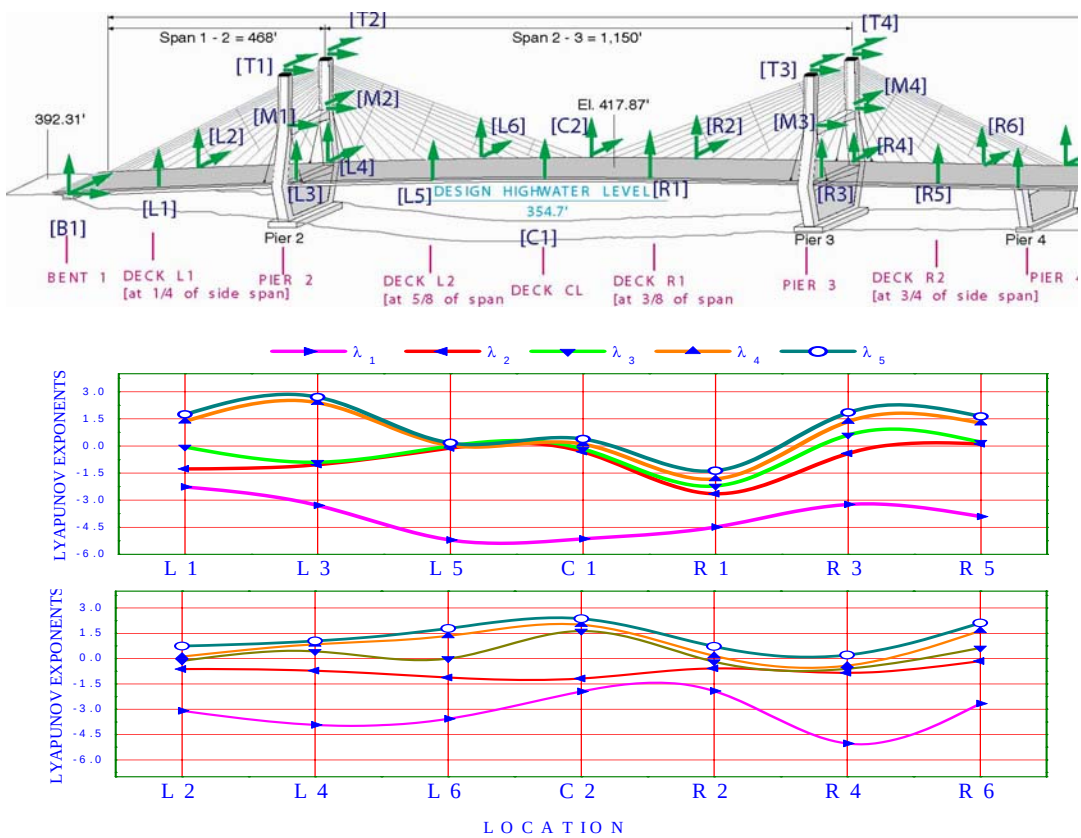
- Analysis of cable-stayed bridge vibration problem (Bill Emerson Memorial Bridge and Fred Hartman Bridge). Cable-stayed bridges can exhibit large amplitude irregular stay cable oscillations under certain traffic flow and rain/wind load conditions. The chaos theory analysis

technique developed in this research has been applied to both the actual field monitoring data sets from the bridge and the simulated bridge responses based on detailed nonlinear FE cable-stayed bridge model to investigate the mechanisms causing this behavior in cable-stayed bridges.

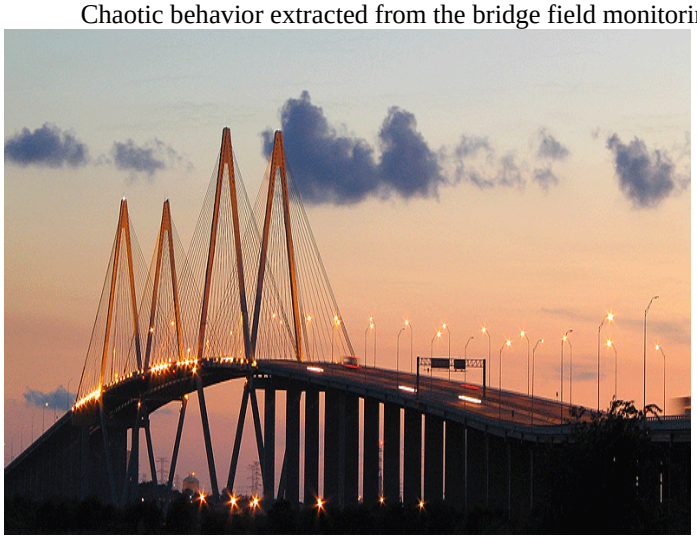


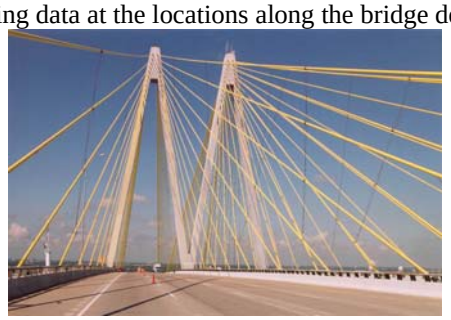


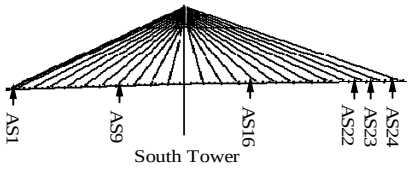
Chaotic behaviors at the nodal locations along the bridge stay cables.



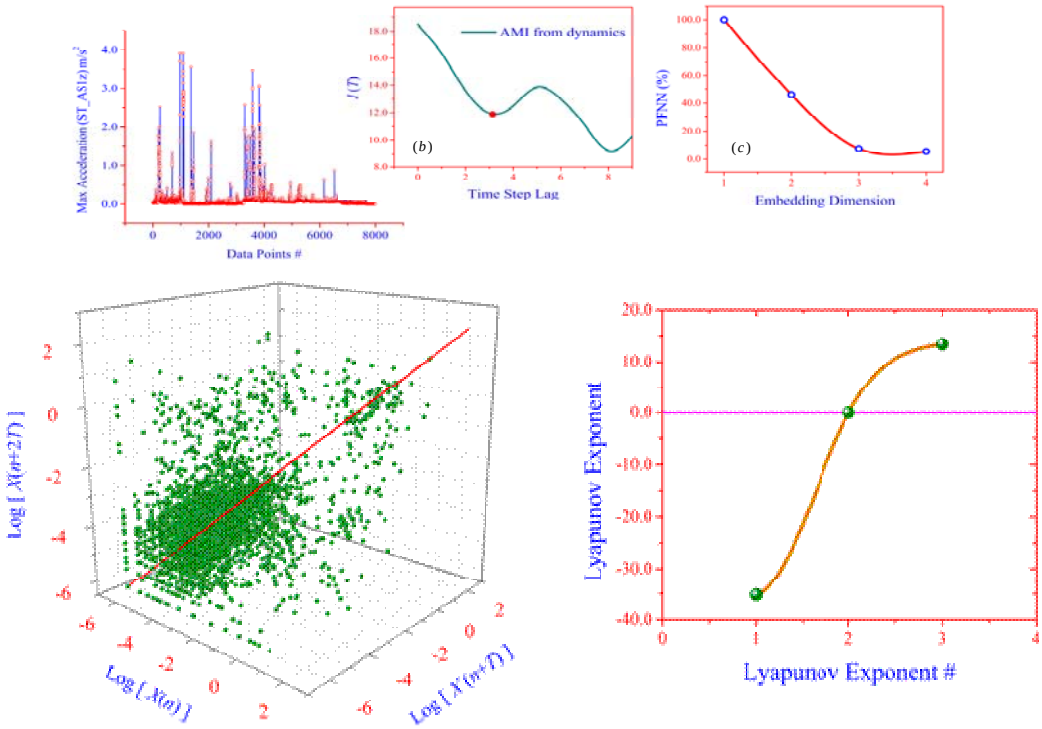
Chaotic behavior extracted from the bridge field monitoring data at the locations along the bridge deck







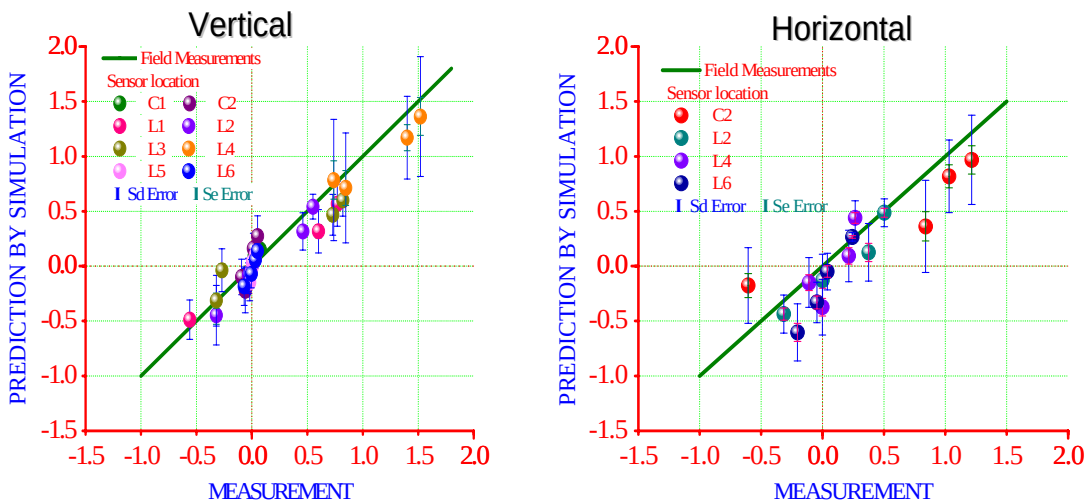
The Fred Hartman Bridge across the Houston Ship Channel in Texas and the locations of some sensors at the stay cable of the bridge



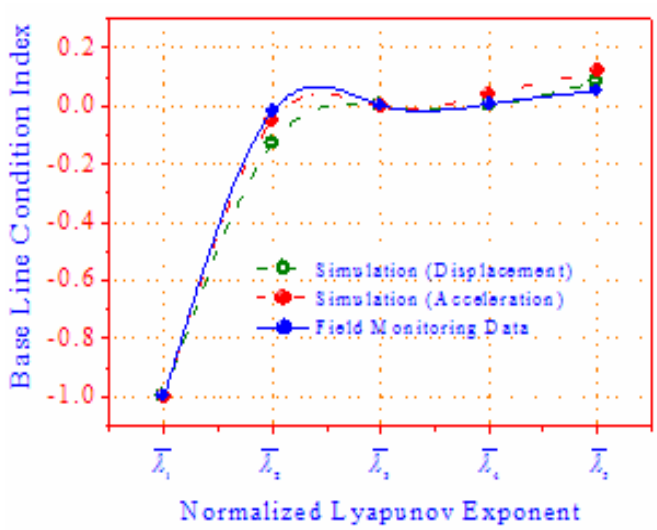
The chaos theory analysis of cable-stayed bridge vibration at the sensor AS1z in the Fred Hartman Bridge

The results in the above figures show significant chaotic behavior in the bridge stay cables and deck vibrations. Since the significant positive Lyapunov exponents also appear at stay cables locations, the irregular chaotic vibrations due to the dynamic interactions between the bridge deck and the networked stay cables are the important concerns.

- Chaos theory analysis for reliable base-line condition in long-term structural health monitoring of highway bridges. This research has found from the analysis of both the computer simulation and the field monitoring data sets that the normalized Lyapunov exponents can be used to form the baseline condition index, as shown below, for reliable long-term structural health monitoring of highway bridges.



Normalized Lyapunov exponents from simulations vs. observations for the horizontal and vertical accelerations at the bridge sensor locations.



The baseline condition index extracted from bridge dynamics simulation and field monitoring data sets.

This research has confirmed that bridges of different structural designs and construction materials can all exhibit complex nonlinear or chaotic behavior under certain complex dynamics and/or environmental load conditions. This nonlinear chaotic behavior may cause structural damages in highway bridges but often cannot be revealed by conventional linear dynamics analysis. Therefore, chaos theory analysis technique is useful in developing advanced smart systems for damage detection, sensor network optimization, vibration control and long term structural health monitoring of highway infrastructure. The research at the NDE Center in the application of chaos theory analysis has more than 24 technical conference and journal papers published (see the list below).

Automated Ultrasonic Testing

A variety of nondestructive inspection techniques has been developed for inspecting welds during the fabrication of steel bridge structures to ensure quality of workmanship. For many years, radiographic testing (RT) has been the preferred NDE method used to ensure the quality of butt welds in the fabrication of steel plates for bridge girders. The major advantage of RT has been the capability of producing a radiograph that serves as a permanent record of the inspection. The shortcomings of RT have been: 1) concerns to the significant health hazards associated with radiation that enforces fabricator to block off a large area of fabrication shop during RT activity, and 2) lack of providing information about depth of defects that impels fabricator to use conventional manual UT to determine depth of defect in order to write up a specific procedure for repair of the weld. Recent advances in computer and ultrasonic technology have led to the development of automated ultrasonic testing (AUT) techniques that produce three-dimensional images of internal conditions in the weld. The AUT image can serve as a permanent record of the inspection and allows for subjective reviews of the inspection findings. Integration of AUT techniques with mechanized scanners and phased array transducers will lead AUT techniques to a fully automated inspection tool which eventually reduces the inspection time considerably.

The outcomes of the AUT research project have proven that: 1) AUT is a viable inspection technique for fabrication inspection of butt welded steel plates for bridge girders, 2) AUT provides more complete information than conventional manual UT and RT (i.e. currently used NDE techniques for fabrication inspection) about the characteristics of the defects in the weld, 3) AUT provides a relatively objective method of analysis, 4) AUT is expected to speed up the fabrication inspection of butt-welds if integrated with mechanized scanners and phased array transducers, 5) there is no known health hazards associated to the use of AUT.

The promising outcomes of the NDE Center's research study on AUT techniques for fabrication inspection have led to a lot of interests by bridge owners and fabricators. However, the AUT technique has not been codified and standardized yet to be used as a replacement for RT and conventional manual UT for butt-weld quality inspection. Therefore, further research studies are required: 1) laboratory testing and evaluation of fully automated AUT techniques (i.e. AUT equipped with mechanized scanners and phased array transducers), 2) expensive study to writing a new codes and procedures for AUT or modifying the existing code to be used for AUT.

Non-Destructive Evaluation (NDE) Laboratory Review Panel Report

DATE: August 27 - 30, 2007

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I. Objectives of the Expert/Peer Review

The expressed objectives of the expert/peer review are to:

- Enhance laboratory and related research program quality, performance, and relevance by providing feedback and suggestions for improvements to laboratory managers;
- Provide an opportunity for exchange of views among technical experts;
- Provide increased opportunities for Federal Highway Administration (FHWA) customers and stakeholders to provide input to research and related program activities;
- Provide a credible, professional, and objective assessment that further improves customer and stakeholder confidence in the conduct of research and the outcomes produced; and
- Strengthen ties with members of the expert/peer review panel and their organizations.

II. Assessment Criteria and Scope of the Expert/Peer Review

To support the FHWA role of "Innovators for a Better Future," TFHRC leadership is committed to invest in and conduct transportation research with and on behalf of partners and stakeholders.

The Laboratory Assessment Criteria are based on three criteria for Federal investment in research established by the Office of Management and Budget. These three criteria are relevance, quality, and performance. The laboratory assessment process at the TFHRC

particularly highlights the quality and performance criteria. The expert/peer reviews are not intended to address what research is being conducted, but rather how the research in which TFHRC is engaged is being carried out. Nevertheless, researchers should have an understanding of how their research supports the agency's mission and meets customer needs.

To prepare for the review, the panel received documentation describing the NDE's program and procedures. Because the work of the laboratory is primarily mission-driven, the team also received information about the mission and goals of the FHWA. This documentation included:

Corporate Master Plan for Research & Deployment of Technology & Innovation.
Guiding Principals and Agency Commitments for the Corporate Master Plan fact sheet.
Handbook for Expert/Peer Reviews
Non-Destructive Evaluation Laboratory fact sheet
Briefing materials sent before the review, including laboratory and research project information, and panel report template.
Upon arrival at the review, a hard copy of Laboratory Briefing Book.

All panel members participated in a telephone conference that was held on August 15th at 1pm (EDT) FHWA staff and the panel facilitator reviewed the proposed agenda and discussed expectations for the review with the panel. The call was also an opportunity for the FHWA staff and facilitator to answer panel members' questions.

Once on site, the review panel received a series of briefings from FHWA staff. These briefings were followed by visits to the NDE Laboratory, follow-on interviews, and meetings with customers and stakeholders over a 2.5 day period. Time was provided for independent fact-finding and investigation by the panel.

III. Non-Destructive Evaluation Laboratory

Federal Staff:

Name	Title	Telephone	Email
Frank Jalinoos	Research Structural Engineer	202-493-3082	Frank.Jalinoos@fhwa.dot.gov

Laboratory Contract Staff:

The Contract staff are employees of Wiss, Janney, Elstoner Associates, Inc (WJE) office and laboratory complex near Chicago offers the most advanced structural and materials testing facilities and equipment for construction related investigations, instrumentation, and research.

On Site Contractor:

Name	Title	Telephone	Email
Paul Fuchs	Research Specialist	202-493-3133	Paul.fuchs@fhwa.dot.gov

Laboratory Contract Staff:

Other Team Members Involved in Working Directly in the NDE Laboratory

Name	Title	Telephone	Email
Mark Moore	Project Manager	202-493-3120	mmoore@wje.com
Ali Rezai	Senior Research Associate	202-493-3119	arezai@wje.com
Shuang Jin	Senior Research Associate	202-493-3152	sjin@wje.com
Brian Story	Senior Research Associate	202-493-3121	bstory@wje.com

A. Overview of NDE

Purpose

Researchers at the Federal Highway Administration's Nondestructive Evaluation (NDE) Laboratory, located at the Turner-Fairbank Highway Research Center, develop and test NDE technologies to assess the condition of highway bridges. This assessment includes evaluating current technologies and developing new tools that will advance the practice of bridge inspection.

Description

The NDE Laboratory is staffed with a multidisciplinary team of experts working on tools and techniques to assess the condition of in-service highway bridges. The laboratory is the only facility in the world dedicated to advancing NDE technologies for highway bridges, and laboratory researchers work closely with State departments of transportation (DOT) across the National to identify and solve difficult inspection challenges.

Areas of research at the laboratory include ultrasonic testing methods, radiographic and nuclear NDE techniques, wireless instrumentation, laser measurement devices, infrared technologies, ground penetrating radar (GPR) systems, and electromagnetic NDE techniques. Researchers also evaluate the reliability and capability of NDE techniques; this includes studying the visual inspection technique and the effects of human factors on reliability.

Major Capabilities

A 465-square meter (5,000-square foot) laboratory equipped with state-of-the-art NDE instruments helps researchers develop and test NDE tools. Seven test bridges located in Virginia and Pennsylvania provide field test sites for NDE technologies. This site includes

two bridges permanently equipped with instrumentation for monitoring bridge conditions and testing new sensors.

B. FOCUS ISSUES

Focus Issue One: Increased Scope of NDE Center

To date, the focus of work at the FHWA NDE Center has been on bridge structures. In part, this focus has been in response to specific needs identified within the FHWA and the states. For example, a review of NBIS data identified deteriorated bridge decks as the most frequent structural condition resulting in a bridge being rated deficient. Accordingly, NDE related research was focused on tools and techniques to assist bridge owners in the assessment of concrete bridge decks. This work resulted in a series of research projects where capabilities of ground penetrating radar (GPR), impact echo (IE), and infrared thermographies (IR) were assessed. As a result of these efforts, improved bridge deck assessment tools have been made available within the NDE community.

In addition, over 100,000 of the approximately 600,000 bridges in the NBIS are rated as structurally deficient. A bridge can also be considered structurally deficient due to a low structural appraisal, or load rating. This problem is compounded by the number of bridges with a lack of plans and limited documentation, most notably unknown foundations that also impact the accurate rating for a bridge structure. The topic of rapid load rating of the undocumented bridges has also been an active research area at the center.

Applying effective NDE tools and techniques to the assessment of existing pavements appears to be a logical extension to the role of the FHWA's NDE Center. While some would suggest that preventing pavement failures is not as critical as identifying deficiencies in a bridge structure, deterioration and failures in pavements directly affect the safety of the roadway system.

Any insight and guidance that the Peer Review Panel can offer on an expanded role for the FHWA NDE Center would be helpful.

Focus Issue Two: Funding and Staffing for the NDE Center

Reductions in designated research funds have been experienced over the duration of the current contract for staffing and operation of the NDE Center. For the last two years of the contract, the FHWA has operated under continuing resolutions resulting in funding uncertainty. The uncertainty of continued funding for research programs like the NDE Center remains. Further impacting the funding issue has been the large number of earmark research projects which, when combined with reductions in designated research monies, have reduced the funds available for research at TFHRC. For example, an earmark research project related to ground penetrating radar (GPR) at a state university resulted in on-going research on GPR at the NDE Center to be discontinued.

One of challenges being faced by the FHWA is how to provide leadership to the State Highway Agencies (SHAs) in key infrastructure research areas and what reliable sources of funding can be utilized. Clearly one approach could be to leverage the in-place assets of the FHWA's NDE Center to support continued NDE related research which would be funded by SHAs through pool fund programs. Nominal investments by the FHWA could be combined with funds from SHAs to conduct targeted research on NDE tools and techniques that could benefit the SHAs. To facilitate the increased scope of activities at the NDE Center, an increase in staffing at both the federal and contractor level will be required.

Any insight and guidance that the Peer Review Panel can offer on increased staffing and funding for the FHWA NDE Center would be helpful.

Focus Issue Three: Coordination of Research Activities and Development of a National NDE Task Force

One of the roles of the FHWA's NDE Center has been to serve as a focal point for NDE related research in the area of highway infrastructure. However, the conduct of NDE related research continues in a somewhat fragmented and disjointed fashion. Within the FHWA, NDE related research has long been well coordinated. However, research work sponsored by other agencies and SHA's have not always been well aligned or coordinated with the FHWA or each other.

One of the other challenge areas that have been identified is the lack of collaboration in on-going NDE related research. While much effort is done to disseminate the results of research work after the research is completed, there is very little effort among current NDE related researchers to collaborate during the work. One of the roadblocks in this area may simply be geographical separation.

It is believed that there is a benefit from an effort by the FHWA to assist and possibly facilitate collaboration by NDE researchers. This assistance could come in several forms including:

- Monitoring and tracking the progress of on-going NDE related research
- Facilitating on-line workshops where researchers exchange information about their work in an informal venue
- Sponsoring short-term exchange programs where researchers visit other facilities and participate in on-going research

While the challenges of these efforts may be significant at first, will the improvements in terms of more effective research will ultimately benefit the entire NDE community.

It is also believed that there is a benefit to forming a National NDE Task Force to coordinate and facilitate NDE research related activities in the US. At issue is should this task force is one of the operational components of the NDE Center. The purpose of this task force can include *specific functions* such as:

- Tracking the progress of the highway related research

- Technical input, review, and improvement of the ongoing NDE Web Manual Project
- Discuss strategies for the more effective deployment of NDE technologies, such as the development of a hands-on practical NDE training course for the bridge inspector community
- Consideration of development of a highway NDE Service Directory Handbook

Any insight and guidance that the Peer Review Panel can offer on an expanded role for the FHWA NDE Center in coordination of research activities and development of a National NDE Task Force would be helpful.

C. Interviews with Stakeholders/Customers of NDE

During the expert/peer review, panel members interviewed a selected group of the laboratory's stakeholders and customers. In addition, discussions were held with these individuals during group settings such as a working lunch. Individuals whose comments were incorporated into this evaluation included the following:

Luncheon Meeting Discussion with Customers for NDE

FHWA Headquarters and Resource Center:

Name	Title	Telephone	Email

Other Customers and Stakeholders:

Name	Title	Telephone	Email

Telephone Interviews with Customers

Name	Title	Telephone	Email

D. Common Themes Emerging from the Interviews and Discussions:

- theme
- theme

- theme
- and so on

E. Observations:

The expert/peer review panel noted several significant strengths of the BMIS Laboratory including:

- strength
- strength
- strength
- and so on

The expert/peer review panel's observations on these issues as well as general topics of research management follow:

- item or issue
- item or issue
- panel members may wish to insert narrative text below or as an attachment to elaborate on the issues and observations

F. Recommendations:

- item or issue
- item or issue
- bullet format provides for an "executive summary" of recommendations
- panel members are invited to insert narrative text below or as an attachment to elaborate on the issues and recommendations

Respectfully submitted,

_____	_____
Chairperson	Date
_____	_____
Member	Date
_____	_____
Member	Date
_____	_____
Member	Date
_____	_____
Member	Date

APPENDIX A

REVIEW PANEL BIOGRAPHICAL INFORMATION

NAME: Larry D. Olson, P.E. (Email – ldolson@olsonengineering.com)

POSITION: Principal Engineer and President, Olson Engineering, Inc.1985 - 2007
Principal Engineer and President, Olson Instruments, Inc., 1995-2007

PROFESSIONAL ENGINEERING REGISTRATIONS AND HONORS:

Registered Professional Engineer: Colorado No. 22,752, Texas No. 55,639, California No. C 041299 (Civil), Arizona No. 27132, Nevada No. 12734 (Civil), North Carolina No. 29251; Member, Academy of Distinguished Alumni of the Department of Civil, Architectural and Environmental Engineering of the University of Texas at Austin, 2006; and, Colorado American Society of Civil Engineers Young Engineer of the Year, 1987

EDUCATION:

B.S. Civil Engineering, University of Texas at Austin, 1978
M.S. Engineering, University of Texas at Austin, 1983 (Geotechnical Engineering Area)

RECENT CONSULTING EXPERIENCE:

Mr. Olson started Olson Engineering, Inc., in 1985 and he serves as a Principal Engineer and President. He has a broad range of expertise in the areas of geotechnical and materials engineering with specialization in nondestructive testing and evaluation and geophysical engineering for the construction industry. He started Olson Instruments, Inc., as a division in 1993 and incorporated it in 1995 to provide NDT&E and geophysical instruments for condition evaluation of infrastructure. Olson Instruments manufactures ultrasonic, sonic, seismic and vibration nondestructive evaluation systems as well as structural health monitoring systems around the world with sales in over 40 countries to date. Since co-founding Olson Engineering, Inc., in April 1985, he has been actively involved in the management and performance of nondestructive testing and evaluation projects for structural condition assessment, repairs consultation, geophysical and vibration engineering, structural health monitoring, forensic engineering, and applied research and development projects.

In the nondestructive testing and evaluation (NDT&E) area, Mr. Olson has conducted investigations to determine the conditions of such facilities as bridges, slabs and pavements, nuclear reactors, buildings, deep foundations, dams and tunnels. He has also performed nondestructive testing of wood and steel pile foundations, masonry structures and steel columns for integrity evaluations. These investigations were performed with seismic, sonic, ultrasonic, electrical, magnetic, ground penetrating radar, infrared thermography, vibration, corrosion activity/rate/concrete resistance, electrical, magnetic and other nondestructive and destructive methods to evaluate internal conditions from quality assurance and forensic troubleshooting perspectives. He has similarly conducted geophysical investigations for karst evaluations and seismic design purposes.

Noteworthy consulting projects include the following NDT&E projects conducted for condition assessment of structures and infrastructure for Olson Engineering clients:

- Principal Engineer for Pilot Technology Transfer Project in JV of Olson Engineering and Ultra Technologies in New Delhi, India for Northern Railways of Indian National Railways. This project involved the classroom training of 28 civil engineers from 13 railways across India on structural condition assessment of railway bridge piers and abutments. A total of 6 concrete and masonry bridges were nondestructively tested and evaluated with 9 NDT&E methods in March, 2006 in the New Delhi area. Detailed reports were submitted on each of the 6 bridges tested.

- Interstate 90 Indiana Toll Road by Gary, Indiana for structural condition assessment of foundations, piers and abutments, beams and girders, and decks of 8 steel/reinforced concrete bridges. Consultation on steel and concrete repair designs for corroded decks, girders, beams, piers and abutments.

- Lincoln and Jefferson Memorials historic preservation studies of the concrete substructure and marble of both memorials as well as vibration damage mitigation and corrosion evaluation studies at the Jefferson Memorial.

- Korean High Speed Rail line construction quality audit of the embankments, bridge foundations and tunnel linings from Seoul to Taejon, South Korea.

- Regional Transit District Southwest Corridor structural condition assessment of 10 pre-stressed, pre-cast box girder bridges for concrete placement and consolidation problems.

- Quality Assurance of underwater concrete placement in drilled shaft foundations for many large bridges across the US and internationally.

- Dam safety evaluations of concrete and masonry conditions with surface waves, velocity tomographic imaging, impact echo and radar methods nationally.

Other types of nondestructive measurement projects performed by Mr. Olson include soil dynamics, modal testing of structures, acoustic vibration monitoring for electronics manufacturing clean rooms and construction activities, and seismic surveys for engineering purposes. He has also performed several specialized studies, one of which involved evaluation of the conditions of low-level radioactive hazardous waste soil/cement blocks.

Specialized design and forensic engineering studies performed by Mr. Olson have included evaluation of foundation distress due to swelling soils, soil dynamics and vibrating machine foundation design, evaluation and material repair recommendations for reinforcing corrosion in concrete structures, void in CRCP pavement, and acoustic vibration studies for electronics manufacturing clean rooms and for construction. The studies utilized both destructive and nondestructive testing methods as appropriate.

RESEARCH EXPERIENCE

Mr. Olson has been active in applied research and development of NDT & E methods since his graduate school research to develop a tool for offshore measurement of seismic wave velocities in marine sediments. Over the years, research activities for Olson Engineering, Inc. have included seven externally funded projects with grants of ~2 million and several internally funded projects. He is currently serving as the Co-PI on an NCHRP IDEA grant for a Bridge Deck Scanner using NDE methods for condition assessment. He just completed serving as a co-PI on an NCHRP IDEA grant for stress wave scanning of post-tensioned bridge ducts to check for void. He completed serving as the principal investigator on a Phases 1 and 2 of NCHRP 21-05 (2) research grant for the Determination of Unknown Bridge Foundations in June, 2001 and submitted the final report on an FHWA study for dynamic evaluation of bridge substructures in 2002. In the 1990's he was the principal investigator in a Phase I NSF Ultrasonic Tomography

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study for concrete flaw imaging. He was also the principal investigator on an USDA Phase I SBIR grant for stress-wave scanning of wood.

Mr. Olson has served as technical consultant on a Phase I research grant by the Maryland Highway Administration to the University of Maryland for NDT of bridges. He has also served as a technical consultant on the SHRP H-104 project that researched and developed the seismic pavement analyzer, a pavement testing device, at the University at Texas at El Paso. He was the principal investigator for a U.S. Bureau of Reclamation grant for impact echo scanning of concrete pipes to identify corrosion of prestressed wire strand.

In 1988, he was the principal investigator of an NSF SBIR grant to evaluate the feasibility of using the Spectral Analysis for Surface Waves (SASW) methods to determine the extent and thickness of frozen and thawed ground. In 1987, he served as principal technical consultant on a joint venture project funded by the National Science Foundations (NSF) Small Business Innovation Research (SBIR) program to nondestructively predict concrete strength by Impact Echo, Ultrasonic Pulse Velocity and Rebound Hammer methods.

PROFESSIONAL ORGANIZATION INVOLVEMENT

In the Transportation Research Board (TRB), he is a member of the AFF40 Dynamic and Field Testing of Bridges Committee, its Nondestructive Testing Subcommittee AFF40(1) and the Geophysics AFP20(1) subcommittee. He is also a member of American Concrete Institute Committees 228 on Nondestructive Testing and 309 Consolidation. Mr. Olson is Chairman of the Evaluation Committee of the International Concrete Repair Institute and a past director of ICRI. He regularly speaks and lectures on nondestructive testing and evaluation applications in civil engineering. He is an ASCE member and since 1997 he has been the instructor on concrete and masonry and occasionally wood materials in ASCE's continuing education program short course "Structural Condition Assessment of Existing Structures" (**http://www.asce.org/conted/seminars/seminar.cfm?cat=7#abc163abc**) which includes visual, destructive, NDT&E and Geophysical methods. Mr. Olson has taught this ASCE class at over 80 locations across the US, in Canada and in Panama to the Panama Canal Authority. He was an active member of the External Advisory Board of the Civil Engineering Department of the University of Texas at Austin from 2000 to 2004 when he served as Chairman.

PRIOR EXPERIENCE:

Mr. Olson was employed with CTL/Thompson, Inc. in Denver, Colorado as a Geotechnical Project Engineer from 1980 to 1985. He was responsible for conducting geotechnical investigations for residential, commercial and industrial sites, and materials investigations of concrete foundations, slabs and pavements, and structures with nondestructive and destructive testing methods. He performed soil and foundation investigations for structures ranging from residential housing to high-rise hotel and office buildings. He designed flexible and rigid pavements for commercial and residential roadways.

Special project groups included investigation of hazardous waste disposal sites; field and laboratory measurement of in-situ dynamic soil properties; machine foundation design for dynamic loading; research on expansive soil properties; and earthquake design. Emphasis was placed on soil dynamics, excavation shoring, geophysical engineering, nondestructive testing of deep foundation integrity, ultrasonic testing of concrete and masonry structures, compaction and chemical grouting, and field investigation techniques.

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SREENIVAS ALAMPALLI
Director, Bridge Evaluation Services Bureau
New York State Department of Transportation
50 Wolf Road, POD 43, Albany, NY 12232
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Dr. Sreenivas Alampalli is the Director of the Bridge Evaluation Services Bureau at the New York State Department of Transportation. His Bureau provides data collection and evaluation services to facilitate the preservation, structural integrity, and safety of existing bridge infrastructure in New York. His responsibilities also include managing Bridge Safety Assurance program, which covers vulnerabilities such as earthquakes, impact, overloads, scour, and security. He also has extensive research experience in design, construction, inspection, and rehabilitation of transportation infrastructure systems. He obtained his Ph.D. and MBA from Rensselaer Polytechnic Institute, M.S. from IIT, Kharagpur, India, and B.S. from S.V. University, Tirupati, India. His interests include infrastructure management, innovative materials for infrastructure applications, nondestructive testing, structural health monitoring, and long-term bridge performance. He authored or co-authored more than 200 technical papers and research reports. He is a Fellow of ASCE and ASNT, and is a member of several technical committees in TRB, ASCE, and ASNT. He also serves as an Associate Editor of the ASCE Journal of Bridge Engineering.

EDUCATION

M.B.A. in Management & Technology (2000), Rensselaer Polytechnic Institute, Troy, NY
Ph.D. in Civil Engineering (1990), Rensselaer Polytechnic Institute, Troy, NY
M.S. in Civil Engineering (1985), Indian Institute of Technology, Kharagpur, India
B.S. in Civil Engineering (1983), Sri Venkateswara University, Tirupati, India

EXPERIENCE

Bridge Evaluation Services Bureau, NYSDOT, Albany, NY
Director, September 2003 – Present
Transportation Research & Development Bureau, NYSDOT, Albany, NY
Director, July 2001 – September 2003
Head, Structures Research, August 1996 – July 2001
Engineering Research Specialist I, August 1990 - August 1996
Rensselaer Polytechnic Institute, Troy, NY
Adjunct Professor, August 2000 – December 2000
Union College, Schenectady, NY
Adjunct Professor, January 1995 - July 1995

AREAS OF INTEREST

Infrastructure Management, Bridge Engineering and Management, Structural Engineering, Innovative Materials for
Infrastructure Applications, Nondestructive Testing, Earthquake Engineering, Instrumentation and Data Acquisition, and
Technology Transfer.

RECENT HONORS AND AWARDS

Registered Professional Engineer - New York State (1993-Present)
Fellow, American Society for Nondestructive Testing, 2005
Fellow, American Society of Civil Engineers (ASCE), 2003
Commissioner's Award of Excellence, 2001
Charles Pankow Award for Innovation, (Team Award), Civil Engineering Research Foundation, 2000
National Steel Bridge Alliance/AISC Prize Bridge Winner: Reconstruction Category, (Team Award), 2000
Exemplary Partnership Award, (Team Award), American Assoc. for State Highway and Transportation Officials, 1999
Finalist, Charles Pankow Award for Innovation, (Team Award), Civil Engineering Research Foundation, 1999
Design Excellence Award, (Team Award), Consulting Engineers Council of NY State, Inc., 1999
Design Excellence Award, (Team Award), Consulting Engineers Council of Delaware State, Inc., 1999

RECENT SCIENTIFIC AND PROFESSIONAL ACTIVITIES

Transportation Research Board
Member and Reviewer (1993-Present)
State Representative for New York State Department of Transportation (2001-2004)
Committee AHD35 on Bridge Management Systems (2004-Present)
Subcommittee AHD35 (1) on Bridge Safety and Security (2004-Present)
Committee AFF40 on Dynamics and Field Testing of Bridges (1998-Present)
Subcommittee AFF40 (1) on Nondestructive Evaluation of Bridges (2000-Present)
American Society of Civil Engineers
Fellow (2003-Present), Member (1990-2002), Reviewer (1990-Present)
Associate Editor, Journal of Bridge Engineering (2003-Present)
Committee on Bridge Management, Inspection, and Rehabilitation (2003-Present)
Committee on Methods of Monitoring and Evaluating Structural Performance (1990-Present)
Committee on Performance Based Design and Evaluation of Civil Engineering Facilities (2000-Present)
American Society for Nondestructive Testing
Member and Reviewer (1992-Present), Fellow (2005-Present)
Director-At-Large, ASNT Board of Directors (2003-2006)
Member and NDT/NDE TWG Coordinator, FHWA Structural Health Monitoring Virtual Team (2004-Present)
Engineering Advisory Council, Wallace H. Coulter School of Engineering, Clarkson University (2005-Present)
Executive Committee, Advisory Board for Multidisciplinary Center for Earthquake Engineering (MCEER), 2005-Present
Member, Peer Review Panel, National Bridge Investment Analysis Software (NBIAS), FHWA (2006)

Wesley S. C. Lum
California Department of Transportation (Caltrans)
Chief, Office of National Liaison
Division of Research and Innovation, MS-83
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Email: wes.lum@dot.ca.gov

Education: B.S. Engineering and M.S. Engineering
University of California, Los Angeles

Relevant Experience:

Mr. Lum has over 30 years experience in transportation at federal, state, regional, city and private levels. He currently manages the Caltrans Office of National Liaison in the Research and Innovation Division and is responsible for incorporating California transportation issues into the national research agenda. Mr. Lum is the current Vice-Chair of the AASHTO Standing Committee on Research and the Chair of the AASHTO Research Advisory Committee.

Mr. Lum recently managed the Infrastructure Research Office that addresses problems in roadways, structures, maintenance, operations, planning and environment. The research involved the customer in the process of finding viable solutions, which helps to deliver recommendations that can be quickly implemented. Examples include a new asphalt concrete specification for the 1996 Quality Control/Quality Assurance construction program, a major accelerated pavement testing program that produced results useful in design and construction of long-life pavements; a seismic ground motion program with private and international partners; and three University Transportation Centers who address issues in transportation policy, systems effectiveness, freight, infrastructure and education/career development. He received the Caltrans Karl Moskowitz Award for outstanding contributions to transportation engineering.

Mr. Lum is also experienced in transportation operations. His responsibilities with Caltrans have made him a leader in Intelligent Transportation Systems (ITS). Projects and programs he has managed are: system architecture design; institutional, environmental and legal issues; freeway operations; statewide operations capital program and traffic management program; Long Range Operations Plans; and technical studies.

Previous management and supervisory Caltrans positions held by Mr. Lum are in highway design and regional planning. Other areas of experience include the Federal Highway Administration and consulting.

Professional Activities:

AASHTO Research Advisory Committee, Chairman 2002-present,
AASHTO Standing Committee on Research, Vice-Chairman 2002-present
AASHTO Region 4 Research Advisory Committee, Chairman 2001- 2002
Transportation Research Board Research and Education Section, Chairman 2004-present
TRB Committees:

- A5017, Library and Information Science for Transportation, 2002-2006
- A5001, Conduct of Research 1999-2006
- A3A01, Communications 1989-1999
- A3B07, Bicycle Facilities 1975-1981

ITS AMERICA, Institutional Issues and Environmental Committees 1991-1995
Institute of Transportation Engineers 1975-present
Registered Civil Engineer, California
Numerous Panels for National Cooperative Highway Research projects

Michael M. Sprinkel P.E.
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Virginia Transportation Research Council
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Phone 434-293-1941
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Email: Michael.Sprinkel@VDOT.Virginia.gov
Home: 513 Georgetown Road, Charlottesville, Virginia 22901

EDUCATION B.S., Civil Engineering, 1972, (with Distinction) University of Virginia

Master of Engineering, Civil Engineering, 1975 University of Virginia

REGISTRATION Registered Professional Engineer, Virginia, 1976 - present

SUMMARY of EXPERIENCE

Michael M. Sprinkel is Associate Director for the Virginia Transportation Research Council, Charlottesville, Virginia where he has served in various research positions since 1972. Since 1992 he has directed the Materials Research Program which includes asphalt, concrete, steel, corrosion and non destructive evaluations. He has conducted research on polymer concrete and hydraulic cement concrete with specialization in the protection, repair and rehabilitation of concrete structures. He was a co-principal investigator for SHRP project C103, “Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques.” He was principal author of the SHRP report "Rapid Concrete Bridge Deck Protection, Repair and Rehabilitation," SHRP-S-344, Washington, D.C., August 1993. He chaired the SHRP Implementation Lead State Team on “Assessment, Protection and Rehabilitation of Reinforced Concrete Structures.” He chaired AASHTO, AGC, ARTBA, Task Force 34 which published the “Guide Specification for Polymer Concrete Bridge Deck Overlays’ AASHTO, Washington D.C., 1995. He was author of "Prefabricated Bridge Elements and Systems," NCHRP Synthesis of Highway Practice 119, TRB, Washington, D.C., October 1985. He has published more than 90 papers. He teaches a short course on “Protection and Repair of Reinforced Concrete Bridge Decks” for ACI and VDOT. He is a Fellow of the American Concrete Institute, Chairman of Committee 503, *Adhesives*, Past Chairman of Committee 345, *Bridge Construction, Maintenance and Repair*, and Member of 546, *Repair of Concrete*, 548, *Polymers in Concrete*, and RTAC, *Repair Technical Activities*. He is a Fellow of the American Society of Civil Engineers. He is the Chairman of Transportation Research Board Committee A2E00 *Concrete*, Member Emeritus of Concrete Committee A2E03, and has chaired and served on other committees. He also has participated in the technical committees of ASBI, ASTM, HITEC, ICRI, PCI, and PTI.

PROFESSIONAL SOCIETIES

AASHTO Chairman Task Force 34 - "Polymer Overlays for Bridge Decks", 1991-1995
Team Leader, AASHTO Lead State Team for SHRP Implementation, Concrete
Assessment and Rehabilitation, 1996-2000.

ACI *Member, American Concrete Institute, 1985-1995, Fellow, 1995 to present*
Member, ACI Committee 548 - "Polymers", 1985-present
Member, Subcommittee 548A - "Polymer Portland Cement Concrete", 1985-2000
Member, Subcommittee 548B - "Polymer Concrete Overlays", 1985-present
Member, ACI Committee 546 - "Repair", 1988-present
Member, ACI Committee 503 - "Adhesives," 1988-present; Chairman 2001-present
Member, ACI Committee 345 - "Concrete Bridge Construction, Maintenance and Repair", 1993-present; Chairman 1996-present
Member, RTAC –"Repair Technical Activities Committee", 2000-present

ASBI *Member of ASBI Grout committee, 2000- present*

ASCE *Fellow, American Society of Civil Engineers, 2005 - present*
Member, 1972-2005
Secretary - Blue Ridge Branch ASCE 1979-83
President Elect - Blue Ridge Branch ASCE l983-84
President - Blue Ridge Branch ASCE 1984-85
Director - Blue Ridge Branch ASCE 1985-86
Award - Most Active Branch in Virginia Section, 1984-85

ASTM *Member, American Society for Testing and Materials, 1986-present*

CERF *Chairman, HITEC Technical Evaluation Panel for Bondade, 1993-1998*
Member, HITEC Standards and Specifications Task Force, 1993-1998

FHWA *Resource Personnel, Technical Advisory Committee on Demonstration*
Project 948, "Polymers for Highway Construction & Maintenance", 1985-1990.
Member, Task Force (Section 6005 ISTEA) - "Thin Bonded Overlays," 1993-1999.
Member, VDOT Value Engineering Team for FHWA Study, "Bridge Deck Maintenance, Repair and Protection," 1989
Member, "Accelerated Construction Technology Transfer" October, 2003 to present.

ICRI *Member, International Concrete Repair Institute, 1990-present*

NCHRP Member, Synthesis Panel NCHRP Project 20-5, Topic 15-10, "Prefabricated Bridge Elements and Systems"

Member, Synthesis Panel NCHRP Project 20-5, Topic 20-12, "Latex Modified
Concrete"
Chairman, NCHRP Project Panel 12-65, "Full-Depth, Precast-Concrete Bridge Deck
Panel Systems" 2002 – present.
Chairman, NCHRP Project Panel C12-41, "Rapid Replacement of Bridge Decks,"
1993-1998
Member, NCHRP Project Panel 10-32, "Durability of Concrete Containing High-Range Water Reducing Admixtures"

PCI *Member, Prestressed Concrete Institute, 1992-present*

PTI *Professional Member, Post-tensioning Institute, 1977-present*
Member of Grout committee, 1995- present

SHRP *Member, Research Team for SHRP Contract C-103, "Concrete Bridge Protection*
and Rehabilitation: Physical and Chemical Techniques," 1988-1994

SPI *Member, The Society of the Plastics Industry, Inc., 1989-1990*

TRB *Member, 1973 to 2001, Member Emeritus, 2002 to present*
Member, TRB Committee A2C02 - "Steel Bridges", 1975-1981
Member, TRB Committee A2F04 - "Construction of Bridges and Structures", 1978-1988; Secretary 1979, 1982, 1985 and 1986;
Chairman, Subcommittee on Research Needs, 1982-1988
Member, TRB Committee A2E03 - "Mechanical Properties of Concrete", 1979-2001; Secretary 1982-1988; Chairman, 1988-1994
Chairman, Subcommittee Research Needs, 1981-1988
Member, TRB Committee A3C14 - "Adhesives, Polymer Concretes and Sealers",
1985-present; Secretary 1985; Chairman, 1994-2001
Member, TRB Group 2 Council Committee - "Design and Construction of Transportation Facilities", 1993-present
Member, TRB Group 2 Council Paper Awards Committee, 1993-present
Chairman, 2002 - present
Chairman, TRB Committee A2E00- "Concrete Section", 2000 – present
Award: Transportation Research Board "K.B. Woods Award," Best Paper in Design and Construction of Transportation Facilities, 1988
Profile in TR News, Number 230, Transportation Research Board (2004)

VDOT *Member, VDOT/VRTBA Joint Highway Cooperative Committee, 1993-present*

AWARDS AND HONORS

- Phi Eta Sigma Honor Society, University of Virginia
- B.S. in Civil Engineering, with Distinction (1972)
- President Blue Ridge Branch when received 1984-85 Award for "Most Activity Branch in Virginia Section" (1985)
- Transportation Research Board "K.B. Woods Award," Best Paper in Design and Construction of Transportation Facilities (1988)
- Fellow, American Concrete Institute (1995)
- Emeritus Member, Transportation Research Board (2002)
- Profile in TR News, Number 230, Transportation Research Board (2004)
- Commonwealth of Virginia Governors Award for “Efforts to Reduce Spending and Make Government More Efficient” (2003)

PAPERS published by the Transportation Research Board (28)

PAPERS published by other Journals (68)

RESEARCH REPORTS published by the Virginia Transportation Research Council, Charlottesville, Virginia (58)

TALKS given at National or International Meetings (134+)

PAPERS OR TALKS given at State Meetings (51+)

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From 1974 to 1979, Dr. Carino was an assistant professor at the University of Texas at Austin. He taught courses in engineering materials science, concrete technology, reinforced concrete design, and advanced strength of materials. He supervised graduate student research in areas such as polymeric concretes, sulfur impregnated concrete, corrosion of steel in concrete, and hot weather concreting.

In 1979, Dr. Carino accepted a position at NIST as a research civil engineer. His research activities have been in the areas of in-place testing of concrete for strength and nondestructive methods for flaw detection in construction materials. He has been involved in fundamental research on the maturity method and the pullout test method. He received a Bronze Medal Award and the CBT Communicator Award in 1983 for his publications related to the maturity method. In 1986, ASTM adopted a standard on the maturity method which was based largely on his work. He was the co-recipient of the American Concrete Institute's Wason Medal for Materials Research in 1994 for work on the maturity method with Dr. R.C. Tank, former guest worker from India. He has conducted research on the use of stress wave propagation to locate defects within hardened concrete. In 1986, he was awarded the ACI Wason Medal for Materials Research for a paper describing the initial research on a new flaw detection technique, which was refined in subsequent research with coworkers, and is now known as the **"impact-echo"** method. He was also co-recipient of the 1987 CBT Communicator Award for a series of papers providing the basis for the impact-echo method. He was a co-recipient of the ACI Wason Medal in 1991 for a paper written with Dr. Mary Sansalone of **Cornell University** which dealt with using impact-echo for detecting delaminations in slabs. In 1998, ASTM adopted a standard test method for using the impact-echo method to measure the thickness of concrete members. His current activities are in the area of high-performance concrete, and he works closely with researchers in Division 862. He has worked with the National Ready-Mixed Concrete Association on experiments designed to provide the technical bases for recommended modifications to ASTM standards to improve their applicability to testing high-strength concrete. Another of his current projects deals with curing of high-performance concrete. The objective is to develop the technical bases for a recommended curing practice that will assure adequate performance, not only in terms of strength but also in terms of durability.

Dr. Carino has been involved in NIST structural investigations. In 1987, he was the project leader in the structural assessment of the new office building of the U.S. Embassy in Moscow and received a Silver Medal Award for his work. He also participated in investigations of the 1981 condominium collapse in Cocoa Beach, Florida, the 1982 highway ramp failure in East Chicago, Indiana, and damage due to the 1989 Loma Prieta earthquake and the 1994 Northridge earthquake.

Dr. Carino is a member of **ASCE** and **ASTM** and is a Fellow of **ACI**. He served on the ACI Board of Direction and was the recipient of the 1993 Delmar L. Bloem Award for "noteworthy accomplishment as a technical committee member and chairman." He served as Chairman of ACI Committee 228 on Nondestructive Testing of Concrete, ACI Committee 306 on Cold Weather Concreting, and the ACI Fellows Nominating Committee. Currently, he is a member of the ACI Technical Activities Committee. He is active in ASTM committee work and has provided leadership in the development of several standard test methods. He serves as chairman of ASTM Subcommittee C09.64 on nondestructive and in-place testing and of the C09.61 task group on testing high-strength concrete. He is coeditor with Mohan Malhotra of the *Handbook on Nondestructive Testing of Concrete* published by CRC Press.

Acronyms

ACRONYM	DEFINITION
AASHTO	American Association of State Highway and Transportation Officials
AWS	American Welding Society
ACFM	Alternating Current Field Measurement
AUT	Automated Ultrasonic Testing
ASNT	American Society of Nondestructive Testing
CAD	Computer Aided Design
CFRP	Carbon Fiber Reinforced Polymer
ConMat	Construction Materials Conference
COTR	Contracting Officer's Technical Representative
CoRe	Commonly Recognized Elements in bridge as defined by AASHTO
CT	Computed Tomography
CTBR	Chaos Theory Analysis of Bridge Response
DOT	Department of Transportation
DR	Digitized Radiography
EEGS	Environmental and Engineering Geophysical Society
FEM	Finite Element Modeling
FHWA	Federal Highway Administration
FIM	Fractal Interpolating Mapping
FO	Functionally Obsolete
GPR	Ground Penetrating Radar
GRS	Geosynthetic Reinforced Soil
HRDI	Office of Infrastructure Research and Development
HRTC	Office of Corporate Research and Technology
IE	Impact Echo
IR	Infrared Thermography
ITS	Intelligent Transportation Systems
LTBP	Long-Term Bridge Performance Program
LTPP	Long-Term Pavement Performance Program
MaxEnt	Enhanced Maximum Entropy
NBI	National Bridge Inventory
NBIS	National Bridge Inventory System at FHWA
NDE	Nondestructive Evaluation
NDT	Nondestructive Testing
NHI	National Highway Institute
NSBA	National Steel Bridge Alliance
PDF	Probability Density Functions
PTC	Pennsylvania Turnpike Commission
QA	Quality Assurance
QC	Quality Control
RD&T	Research Development and Technology
RTR	Real-Time Radiography
SD	Structurally Deficient

SEG	Society of Exploration Geophysical
SHA	State Highway Administration
SHM	Structural Health Monitoring
STAR	Safety Testing and Research Facility
TCC	Text Control Center
TFHRC	Turner-Fairbank Highway Research Center
TRB	Transportation Research Board
USDOT	United States Department of Transportation
UT	Ultrasonics Testing
WJE	Wiss, Janney, Elstner Associates, Inc.