## Federal Highway Administration

Exploratory Advanced Research Program

EXPLORATORY ADVANCED RESEARCH

# NDE Virtual Laboratory Development Workshop Summary

TFHRC, McLean, Virginia – December 19, 2011

U.S. Department of Transportation
Federal Highway Administration

# FOREWORD

The Federal Highway Administration's Exploratory Advanced Research (EAR) Program addresses the need to conduct longer term and higher risk breakthrough research with the potential for transformational improvements to plan, build, renew, and operate safe, congestion free, and environmentally sound transportation systems. The EAR Program serves as an important complement to field-based, applied research programs, such as the Long Term Bridge Performance (LTBP) Program. The EAR Program can accelerate and advance innovative methods by changing the mechanisms used to conduct research and the group of people who have access to research tools by leveraging new information science and communications technologies.

On December 19, 2011, at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA, the EAR Program and Office of Infrastructure R&D convened a 1-day workshop to consider the value of and process for developing a national virtual laboratory for nondestructive evaluation (NDE) for highway structures. The purpose of the workshop was to further define the concept of a national virtual research laboratory for NDE of highway structures and pavements. A national virtual research laboratory would provide a mechanism for researchers from different academic institutions, Government agencies, and industry to coordinate and cooperate on NDE research, more effectively and quickly build on and advance work conducted by others, and increase access for new investigators into NDE research. All of these benefits substantially increases the potential for breakthrough approaches and improved movement of research from the laboratory to field testing and commercialization.

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16. Abstract

On December 19, 2011, at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA, the Federal Highway Administration's (FHWA) Exploratory Advanced Research (EAR) Program convened a 1-day workshop to consider the value of and process for developing a national virtual laboratory for nondestructive evaluation (NDE) for highway structures.

A national virtual laboratory could include test and sample protocols to allow comparison and validation of research done at different locations, research data and metadata to allow future researchers and students to analyze or re-examine results, and analysis and visualization tools to aid in examining and reporting research data.

Previously, FHWA's EAR Program sponsored a National Research Council Associate to conduct a project, "NDE for corrosion detection in reinforced concrete structures incorporating time-resolved thermography combined with three-dimensional (3-D) microwave imaging" at TFHRC's NDE Laboratory. The EAR Program then supported a workshop addressing the use of NDE tools at the Transportation Research Board's 2011 Annual Meeting. The December 19th workshop was held to advance the findings from these efforts regarding an NDE Virtual Laboratory.

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## Table of Contents

# Introduction

On December 19, 2011, at the Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA, the Federal Highway Administration's (FHWA) Exploratory Advanced Research (EAR) Program convened a 1-day workshop to consider the value of and process for developing a national virtual laboratory for nondestructive evaluation (NDE) for highway structures.

Following a January 2011 Transportation Research Board workshop on NDE for bridge maintenance, the EAR Program and Office of Infrastructure Research and Development's (R&D) Infrastructure Management Team invited a small group of national experts to meet at TFHRC to further define the concept of a national virtual research laboratory for NDE.

A national virtual research laboratory comprised of common physical and virtual experiments could allow researchers from different academic institutions, government agencies, and industry to coordinate and cooperate on NDE research. It could more effectively and quickly allow researchers to build on and advance work conducted by others as well as increase access for new investigators into NDE research.

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# Discussion

Following initial introductions and an overview of the background experiences of each workshop participant, discussion focused on the following key areas: the potential benefits of a virtual NDE laboratory for highway structures; potential research topics and critical questions; and options for participation and management structure. An overview of next steps, funding, and potential timing was also provided.

# Potential Benefits

## Research Community and Education

- Virtual laboratories can mobilize many different people. While access to large bridges can be difficult, and owners can be hesitant to share bridge data, the advantage of virtual laboratories is that even students can have access to bridge data.
- Virtual laboratory experiments can be downloaded and performed individually. They also offer remote experiment monitoring and control, online laboratory notebooks, enhanced security, collaboration opportunities, and cross-platform compatibility.
- A virtual version of a bridge structure with sensors, instrumentation, and implemented damage allows researchers to put sensors at any point and then run the structure in the laboratory.
- Virtual problems enable researchers to look at the best sensors to deal with a real-world issue.
- Although nothing can replace hands-on work and physical demonstrations, it is not always possible to do everything in the physical world because of cost and time limitations.
- A virtual experiment can run at the same time as a physical test using the same location and configuration, and it will generate the same data.
- It is possible to mix virtual with real-world data by taking individual components and forming a connection between the simulation of one component and the real data—there are endless possibilities when mixing real and virtual components.
- Although results may not always be 100 percent accurate, a virtual tool to simulate well-established technologies in different areas would at least provide a useful warning light. A virtual environment is a good place to identify defects and measure exactly what is needed.
- The virtual environment allows a user to speed up time in the virtual world. This allows a user to run a test and produce results faster.
- Accelerated testing should be monitored carefully to avoid reinforcing unrealistic data over time.
- A virtual laboratory provides an opportunity to look at different perspectives and come up with a uniform solution.
- A virtual system offers a convenient way of experimenting with many sensor locations and types.
- When performance of a new sensing technology has been validated, hundreds of sensors can be installed in a virtual laboratory.

## Broader Practitioner Community (e.g., engineers, asset owners and operators, commercial vendors)

- If synthetic tests are conducted on a virtual bridge and confirm that a measurement is effective, this can lead to the development of sensors. The virtual laboratory could provide opportunities for the sensor community to develop new sensors.
- There is value in using a virtual laboratory as a tool to aid communication between the researcher and practitioner.
- Generating raw data from virtual experiments could be of benefit to many different groups, including researchers, practicing engineers, and service providers.
- NDE simulations help to develop new analytical procedures but can also be instrumental to others who are not familiar with how different technologies work.
- Implementing a virtual laboratory uses technology to bring end users and researchers together to establish the best approach in an easy and cost-effective way.
- A virtual bridge with a realistic catalog of calibration and damage modules could be very useful to the wider community.
- A virtual structure can have input from many people and therefore utilize many different ideas and contributions.
- The concept of reliability-based inspection was discussed and how a virtual resource could potentially improve management of the inspection process.
- The importance of providing training was highlighted. Owners need to have a good understanding of what technologies are available to them.
- With sufficient funding, a virtual model can be a very useful marketing tool.
- A virtual model can help in asset management; specifically, predictive modeling, deterioration, life-cycle cost modeling, and application of repair and rehabilitation. It is expected that the Long-Term Bridge Performance (LTBP) Program data will provide future data for this.
- Virtual laboratory tools can easily illustrate benefits, predictions, and frequency of testing needed.
- There is a need to detect tiny changes, not just that half the bridge has fallen down. For example, one small change in a physical parameter will influence a certain feature; so by looking at that feature, users can direct resources at determining what should be inspected more frequently.
- Using an interface, a user can select a structure, simulation type, and then choose the forcing type, damage type, and location of sensors and forcing. The interface allows a user to choose the technology and then run the simulation accordingly.
- A virtual system would be expandable and allow the possibility of extra options to be factored in without limiting the choice of potential sensors—there is no limit on its ability to handle new technologies.

- A virtual model allows the user to increase uncertainty for future outcomes—something that is easy to simulate but difficult to conduct in a physical test.
- A new type of sensor could be brought in and tested on a virtual structure.

# Potential Research Topics and Critical Questions

## Implementation Issues

- One of the challenges is the problem of overselling the effectiveness of a virtual laboratory. It was claimed that some well-meaning people have destroyed the credibility of the virtual testing field, and owners are now reluctant to touch it because they have been burned so many times previously.
- Addressing barriers to implementation was highlighted as one of the primary problems to address. Most current research is on the development of technologies, but an ongoing challenge is taking them a step further by implementing them and finding customers willing to use them.
- The LTBP Program was used as an example of implementing different ways to make clients feel comfortable using tools in an operational context. One of the advantages of this program is that it can help stakeholders to get education, training, and demonstrations of technologies. There should be further discussion as to how to move those tools forward.

## Further Investigation

- Although there is no substitute for a physical test, virtual testing works well as a form of leverage. However, due to the fact that damage is nonlinear and an uncertain phenomenon, it is unrealistic to expect to deliver something 100-percent reliable to work within a practical way. It is important to use nonlinear damage modeling, incorporating environmental and temperature conditions.
- The limitations of a model need to be clearly pointed out—this is considered more important than knowing its strengths.
- Participants questioned the frequency of inspections—specifically, is it necessary to inspect the whole bridge every 2 years, instead of some elements every 5 years and others sooner?
- It was noted that there needs to be further research into the long-range development of tools that allow risk-based inspection on demand.
- Protocols for specific types of deterioration need to be developed.
- The issue of computational and physical calibrations was discussed. A good way to calibrate analysis tools could be to introduce delamination at a particular location and then see what is capable of detecting this fault. If a model is not able to perform successfully with synthetic data, with no noise or uncertainty, there is no point in going any further.
- The issue of what should be measured to establish the health of the bridge was also discussed. Money is being spent on collecting certain types of measurement, but it is possible they may be the wrong measurements to be collecting. For example, is deflection more important than acceleration or wave propagation? A virtual model could help establish this.

- The concept of using tools that can reveal damage signatures was highlighted as something that can be very instructive. Establishing the probable cause of a signature that has been observed could be an important feature of a virtual lab.
- It was noted that although it is possible to perform accurate simulations at the component level, problems arise once it becomes a complete system.
- It was noted that almost all current measurement methods rely on anomaly detection, or the need to know the initial state of response. It is important to move away from relative measurements to absolute measurements.
- One of the main challenges facing researchers will be to organize vast amounts of information and access multiple databases. There are many challenges involved with different measurements from multiple bridges with thousands of sensors. It is also necessary to establish how to handle all that information. For example, to only store what is critical over a lifespan of 70 years as historic diagnostic information.
- The evolution of virtual technology in other arenas, such as gaming and defense, was discussed. For example, the ability to simulate different kinds of terrain in virtual worlds is one such available technology that could possibly be harnessed for a virtual laboratory.

## Ongoing Needs

- There is a need to establish the requirements of a virtual NDE laboratory to meet the needs of both owners and researchers.
- There is a need to focus on coming up with something that shows the implication of decisions.
- Through discussions with stakeholders, owners, and engineers, it is important to establish exactly what questions NDE can answer.
- Building a virtual laboratory also requires an appreciation of the complication of the process—it was compared to the realm of a National Aeronautics and Space Administration project, with a high level of epistemic uncertainty.
- There is a need to be edgy and cautious—there should be reasonable expectations and awareness about the ability of a virtual laboratory effort to simulate reality.
- There is a need to recognize every system that is contributing to a single measurement. For example, a bridge has intrinsic forces that can be ten times greater than any truck can cause, and these move all the time like ocean currents.
- A lot of homework is required to make a meaningful assessment and tell an owner something meaningful from that assessment.
- There is a need to determine what is driving the data collection process for a virtual laboratory. What should be done with data and how should they be used to create knowledge and decision support tools? It is important to focus on what a virtual laboratory is trying to address and come up with three to four fundamental categories.

- There needs to be a general framework within which different experimenters can collaborate. It was noted that currently there has never been collaboration between manufacturers of sensor technologies and owners. It was also noted that there is no national-level bridge health index.
- There is a need to establish guidance as to how sensing networks should be utilized in the future (e.g., how frequently measurements should be taken).
- There is a need to have a database with all this information in one place.
- The concept of research needs as grand challenges within a big picture or vision was also discussed. It may be difficult to transition between cautions about the limitations of modeling and simulation and the support for solving grand challenges.
- People have to be trained and have continuous involvement with advanced technologies to fully improve understanding. It is not acceptable to casually drop someone in to do a NDE survey every few months.
- Guidance needs to be developed for practicing engineers to provide realistic expectations.
- It is necessary to build a critical mass of expertise to educate asset owners about NDE.

## Moving Forward

- It was suggested that a matrix, or glossary, of technology could be a useful resource toolbox to address common problems. When all technologies are put in the form of such a toolbox, it is possible to see how different technologies come together and make sense.
- Establishing performance measures is an important step. A majority of preservation money is spent on decks, so that could be a good starting point as a common research topic to test and evaluate ideas. For example, what are the performance indicators and measurements of a bridge deck? Simulation and modeling could be an important first step to later hit the ground running.
- It was suggested that the EAR Program could potentially provide the required resources to remove the barriers to implementation currently faced by researchers.
- It was noted that it would be useful to identify a few key areas where a virtual laboratory would be effective, then use those areas as examples by collecting data and turning it into knowledge that can help owners make decisions. The critical point is to identify the questions to answer and demonstrate the limitations.
- One suggestion was to instrument a new bridge as it is constructed. Known defects from a bridge with problems could also be introduced. This could be opened up as a real test specimen and a virtual laboratory. Researchers could then see if their technology is able to address any of the problems.
    - If it works synthetically, they could then get a grant to demonstrate it in the real world.
    - It would also be useful to look at bridges with no deterioration and then try to identify why that bridge is behaving so well.

- The creation of a standard model for a certain type of pier could be one way to proceed. Then models for the sensors, or different types of loading/deterioration levels, could be factored in.
    - This could begin with a standard bridge, then realism could be gradually added in, followed by different versions featuring additional complication.
    - Damage could be introduced, and users could search for the signature.
- It was highlighted that a wealth of existing data from both physical experiments and models is available to be built on.

## Options for Participation and Management Structure

### Organization

- An effective system architecture needs to be planned at an early stage. The system needs to be adaptable and adjustable to allow for later versions.
- How this project could actually work as a business model was also discussed. With many different potential models available, it is important to establish whether this is something that would be open to the public (e.g., Wikipedia), or would be run out of TFHRC, with tightly controlled content (e.g., so the government is not criticized for promoting a vendor).
- Building a virtual laboratory requires a multicultural/multidisciplinary partnership to oversee the laboratory.
- Cyber-ShARE was put forward as an example of a useful tool for sharing model data between participants.

### Potential Cautions

- Equipment needs to be working all the time and software must be robust.
- There are a lot of good tools already available, and it would be wasteful to dedicate time and resources to "reinventing the wheel." It was added that it does not matter where the assets come from when looking for a specific solution.
- It is essential to bring everyone together to agree in advance on objectives and expectations for a virtual laboratory project (e.g., owner, industry, and academia).
- There is a need to clarify NDE-related terminology. Several terms, including NDE and Structural Health Management, can be used in different ways.

### Administration

- The protocol for data formatting and features (e.g., the ability to import or export data) needs to be established early. These are considered significant issues that should be planned from the very beginning. For example, every proposal that goes to the National Science Foundation (NSF) requires a statement as to how the data will be exchanged and distributed.
- There is a need to come up with a scope and definition of what needs to be accomplished and then prepare a proposal that would include the team that addresses the problem in the best way.
- The importance of actively engaging the industry and high-end technology providers was discussed. This should start at the proposal level and include workshops and information sharing, as well as input on final products and marketing.
- Through discussions with stakeholders, owners, and engineers, it is important to establish exactly what questions NDE can answer.

## Potential Participants

- The University Transportation Center program was highlighted as a network that could offer a lot of leverage and provide an effective mechanism for accessing a broad team, sharing resources, and educating customers.
- The Transportation Pooled Fund program was suggested as a useful resource for supporting studies.
- Securing support from the American Association of State Highway and Transportation Officials was flagged as an important step in the planning process and to help secure the necessary stakeholders.
- It was noted that the American Society of Civil Engineers (ASCE) embodies the entire community of contractors and material providers, so maintaining a linkage with this group would be beneficial. ASCE has a continuing education mission which could help with the education component of this project.
- There would also be great value in having some connection with NSF—it was claimed that its multidisciplinary resources can "excite deep thinkers."
- Other participants to consider could also be the Local Technical Assistance Program and the National Highway Institute.
- It was also noted that the European Commission has several NDE programs potentially of benefit to this research.
- A recommendation was made to not focus solely on North America but to adopt a mechanism for wider international participation.

## Next Steps and Potential Timings

- Next steps will include putting together an outline of what the virtual laboratory could look like. This outline will provide an overview of what the intent is, how it could work, the technical purpose, and discussion in terms of structure and interaction.
- Next, a request for information (RFI) would be made available to see who is interested and in what area. This RFI would be kept open for some time before a follow up with a larger workshop and solicitation for seed funding.
- In terms of timing, the RFI could be formed over FY 2012, and the EAR Program could put out seed funding in FY 2013. The funding would be made available for those uploading the core data as well as those on the back end (e.g., IT support, servers, and logistics).

## About the Exploratory Advanced Research Program

FHWA's Exploratory Advanced Research (EAR) Program focuses on long-term, high-risk research with a high payoff potential. The program addresses underlying gaps faced by applied highway research programs, anticipates emerging issues with national implications, and reflects broad transportation industry goals and objectives.

To learn more about the EAR Program, visit the Exploratory Advanced Research Web site at www.fhwa.dot.gov/advancedresearch. The site features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

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