Monitoring and Sensing of Near-Collapse Buildings Workshop

Homeland Security
Science and Technology

University of Mississippi

INTRODUCTION

Because science and technology are crucial to mitigating natural and manmade effects on critical infrastructure and ensuring the continuity of their services, the U.S. Department of Homeland Security (DHS) Science and Technology (S&T) Directorate has established a goal to accelerate the delivery and understanding of enhanced technological capabilities. In support of this goal, the Infrastructure and Geophysical Division (IGD) of the Science and Technology Directorate, U.S. Department of Homeland Security established a program to investigate the enhancement of building stabilization after an improvised explosive device (IED) attack. To that end, DHS S&T sponsored the 2010 Monitoring and Sensing of Near-Collapse Buildings Workshop.

Through white paper discussions and breakaway sessions, participants in the workshop investigated the critical monitoring and sensing technology for assessing the stability of a building struck by an IED to interpret, analyze, and distribute data, in real- or near-real-time. The availability and transfer of information is vital to stabilizing a structure for rescue efforts.

The results of this workshop will be used to create a research clearinghouse and a state-of-the-art report outlining the available and potential technology that could be used to aid first responders in the stabilizing buildings. These efforts are anticipated to lead to a technology transfer to the private sector, which will allow the rapid deployment of products to stabilize buildings after they have been impacted by IEDs.

The Infrastructure and Geophysical Division of the Science and Technology Directorate, U.S. Department of Homeland Security would like to thank the University of Mississippi in Oxford for hosting the conference and providing space and support.

Ruth M. Doherty, Ph.D.
Program Executive Officer
PEO (C-IED)
U.S. Department of Homeland Security

Stephen D. Hancock
Director for Program Integration
PEO (C-IED)
U.S. Department of Homeland Security

ACKNOWLEDGEMENTS

Many abstracts were submitted to the workshop committee for consideration in response to the call for abstracts. All abstracts were reviewed by two independent reviewers. Some of the review considerations were originality, completeness, and suitability to the workshop goals. IGD acknowledges the efforts of the reviewers in this process. They provided expert technical opinions in a timely manner. Their efforts helped to ensure high quality presentations and achievement of this workshop's desired goals.

IGD would also like to express thanks to the workshop committee for their diligent efforts in organizing and successfully carrying out this workshop. The committee is:

- Mila Kennett, Program Manager, DHS/S&T/IGD
- Tom Coleman, DHS/S&T/IGD
- Eric Letvin, Project Manager and Facilitator, URS
- Mohammed Ettouney, Senior Technical Advisor and Coordinator, Weidlinger
- Holly Stone, Senior Technical Advisor and Coordinator, Stone Security Engineering
- Gwendolyn Hall, Senior Advisor and Logistic Coordinator, URS
- Fernando Cortez-Lira, Systems Engineering and Technical Assistance Support, Analytical Research LLC
- Tate Jackson, Senior Engineer and Workshop Support, URS
- RJ Walker, Workshop Support, URS
- Laura Seitz, Workshop Support, URS

IGD would also like to thank our hosts at the University of Mississippi for their support in organizing this workshop. The host committee is:

- Alice Clark, University of Mississippi
- Alexander Cheng, University of Mississippi
- Chris Mullen, University of Mississippi
- Ahmed Al-Ostaz, University of Mississippi

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Day 1 – Tuesday, April 6, 2010

Theme: The first day of the workshop concentrated on the state of the art and knowledge gaps in monitoring and sensing technologies. This included a) monitoring and sensing technologies currently available to collect, analyze, and disseminate information on site, b) monitoring and sensing technologies currently under development that could be useful, and c) the current state of practice for remote versus on-site sensing technologies.

7:30 Registration

8:00 Welcome and Introductions

Milagros Kennett – DHS, S&T/IGD
Alice M. Clark – Vice Chancellor for Research and Sponsored Programs
Alexander Cheng – Dean, School of Engineering

8:30 ***Session 1*** Problem Definitions

Keynote: *Matt Haupt*
Building Stabilization Effort after IED Attacks

Eric Letvin
Building Stabilization: An Integrated Approach

9:45 Break

10:00 ***Session 2*** Overview of Sensing, Monitoring, Damage Identification and Needed Information for Near-Collapse Buildings

Mohammed Ettouney for Sreenivas Alampalli
Sensors in Civil Infrastructures and Their Potential Utilization for Near-Collapse Buildings: The Basics

Peter Vanderzee
Adopting Commercially Available Sensing and Monitoring Technologies

Elizabeth Ervin
From Sensing to Damage Identification in Unstable Buildings

Hollice Stone
Building Stability Information Needs, Hazard Assessment, Mitigation, and Monitoring in Near-Collapse Buildings: Current Approach from the US&R Engineer's Perspective

Peter Keating
Near-Collapse Buildings: From Sensing and Monitoring to Information for Stakeholders

12:05 Lunch

1:30 ***Session 3*** Current Practices

Richard Christenson
Online Monitoring Framework for Structural Identification and Damage Detection

Michael Barker
Real-Time Remote Monitoring of Compromised Structures during Catastrophic Events

Wayne Haase
Collapse Prediction System for Structural Fires

2:45 Break

3:00 ***Breakaway Sessions***
1A: Sensors
1B: Needed Information
1C: Structural and Damage Identification

5:00 Break

5:30 – 6:00 Moderators and co-moderators meet to prepare for reporting to general assembly next morning

6:30 Short sightseeing tour of Oxford,
Double-decker bus pickup in front of Inn at Ole Miss

7:00 – 8:00 Reception at Southside Gallery, Oxford Square
(Double-decker bus will discharge passengers on location)

8:00 Dinner on your own at Oxford Square (many restaurants)

Day 2 – Wednesday, April 7, 2010

Theme: The second day of the workshop concentrated on a) the information emergency management personnel need, including the type and priority of information needed as well as the form in which emergency management personnel need information transmitted, b) the information that would cause emergency management personnel to suspend or discontinue a rescue or stabilization effort, c) the role of uncertainty in real-time decision-making, and d) the method by which information is communicated to the structural engineer and other stakeholders. In addition, the workshop attendees deliberated the monitoring and sensing technologies that need to be developed to better process information. This included a) the data needing to be sensed and collected, b) damage identification methods of near-collapse buildings, c) structural identification/analysis methods of near-collapse buildings, and d) pre-event versus post-event sensors (deployed by emergency management personnel and FEMA Urban Search & Rescue [US&R] personnel).

8:30 Reporting of Day 1 sessions and resolutions Introductions to Day 2

9:00 ***Session 4*** Equipment and Techniques

Vincent Chiarito
Monitoring Damaged Buildings for Assessing Structural Integrity

Peter Keating
Techniques and Equipment for Monitoring Damaged Structures

Michael Barker for Blake Rothfuss
Case Studies and Lessons Learned from Structural Monitoring of Compromised Structures Following Catastrophic Events

10:15 Break

10:30 ***Session 5*** Modern Sensing Technologies for Near-Collapse Buildings

Dan Rubenstein
EnHANTs: An Energy Harvesting Sensing and Monitoring System for Tracking Applications

Atef Elsherbeni
Millimeter Wave Reflectarray Technology for High-Resolution, See-Through-Wall Imaging Systems

Chung Song
Implementation of a Ubiquitous System to Monitor Near-Collapse Buildings

11:45 Lunch

12:50 ***Session 6*** The Future of Sensing of Near-Collapse Buildings: From Detection to Decision Making

Mohammed Ettouney
Sensing, Structural Identification, Damage Identification, and Decision Making for Near-Collapse Buildings: Challenges for a Comprehensive Approach

Greg Easson
Rapid Building Damage Assessment from Remotely Sensed Imagery

Andrew Zimmerman for Jerome Lynch
Opportunities and Challenges in Monitoring the Health and Stability of Civil Structures Near Collapse

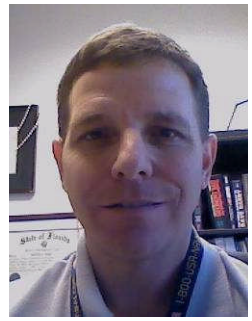
Earle Kennett
BIM Basics and Utilization for Stabilization Efforts

2:20 ***Breakaway Sessions***
2A: Real Time and Near Real Time Decision Making
2B: Knowledge Gaps and Future Challenges

3:15 ***General Assembly and Resolutions***

3:45 ***Adjourn***

Matt Haupt



Matt Haupt, PE, BSCP, is the Anti-Terrorism/Force Protection Team Leader for the URS Corporation in Gaithersburg, Maryland. He has more than 20 years of experience in multi-hazard mitigation and design, serving Federal, State, and local clients. He has experience in infrastructure risk assessments, hazard/threat identification, vulnerability assessments, and the design of protective measures for man-made threats and natural hazards. He has participated in disaster contingency work including the Loma Prieta Earthquake, Hurricanes Hugo, Andrew and Katrina and Mount Pinatubo Volcanic Eruption.

Mr. Haupt is part of a subject matter expert team working with the Department of Defense (DoD). He regularly teaches courses in building design in disaster-resistant construction for FEMA throughout hurricane-prone regions of the United States.

Mr. Haupt is a Commander for the U.S. Naval Reserve and is presently the contingency engineer for U.S. Africa Command. Prior to that, he performed as the Contingency Engineer for Commander Naval Forces Europe, Commander Naval Forces Africa, and Commander SIXTH Fleet, Detachment 108, in Naples, Italy. He performed battle damage assessment for the Republic of Georgia after Russia attacked that nation. He is a plankowner for the Contingency Engineering Unit for U.S. Africa Command, and has performed numerous risk assessments in Iraq, Afghanistan, Europe, and Africa.

Mr. Haupt holds a bachelor's degree in Ocean Engineering from Florida Atlantic University, and masters degrees in Environmental Engineering from University of South Florida and Strategic Studies from the Navy War College in Newport Rhode Island.

Keynote – Building Stabilization Effort after IED Attacks

The keynote presentation is a discussion of Mr. Haupt's experience with near-collapse buildings in Iraq and Afghanistan. The presentation is not available for these proceedings.

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Eric Letvin

Eric Letvin, PE, Esq., is a Principal Engineer and Attorney for the URS Corporation in Linthicum, Maryland. He has more than 15 years of experience in multi-hazard mitigation and design, serving Federal, State, and local clients. He has experience in infrastructure risk assessments, post-disaster forensic analysis, hazard/threat identification, vulnerability assessments, and the design of protective measures for man-made threats and natural hazards. He served as project manager of the FEMA/ASCE team that performed the engineering study of the World Trade Center disaster, and has participated in numerous post-disaster studies including the bombing of the Murrah Building in Oklahoma City, Hurricanes Opal, Ike, and Katrina. He has assessed over 200 buildings for risk from terrorist threats and natural disasters.

Mr. Letvin is part of the subject matter expert team working on the development of the rapid visual screening tool with FEMA, DHS' Science & Technology Directorate. He is the program manager for URS's contract with DHS' Protection and Programs Directorate (Office of Infrastructure Protection). He regularly teaches courses in building design in disaster-resistant construction for FEMA throughout hurricane-prone regions of the United States. He has taught FEMA's Building Design for Homeland Security Course, which teaches students how to conduct risk assessments of critical infrastructure and design protective measures, 23 times to over 400 people in the past 5 years.

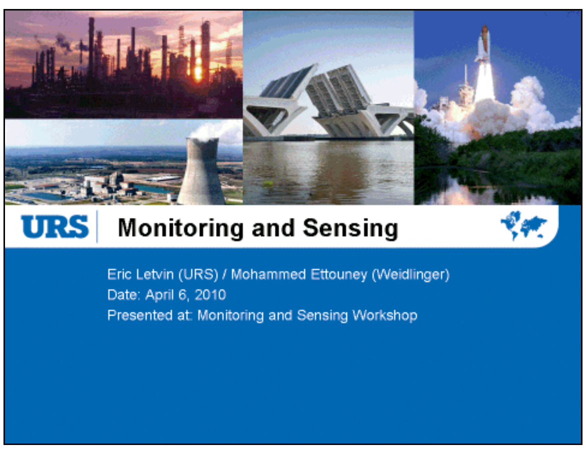
Mr. Letvin has been the consultant project manager for numerous FEMA mitigation publications including the recently released FEMA 453, Design Guidance for Shelters to Protect Against Terrorist Attacks; FEMA 426, Reference Manual to Mitigate Potential Terrorist Attacks Against Buildings; FEMA 452, Risk Assessment: A How-To Guide to Mitigate Potential Terrorist Attacks; and FEMA 428, Primer to Design Safe School Projects Against Terrorist Attacks.

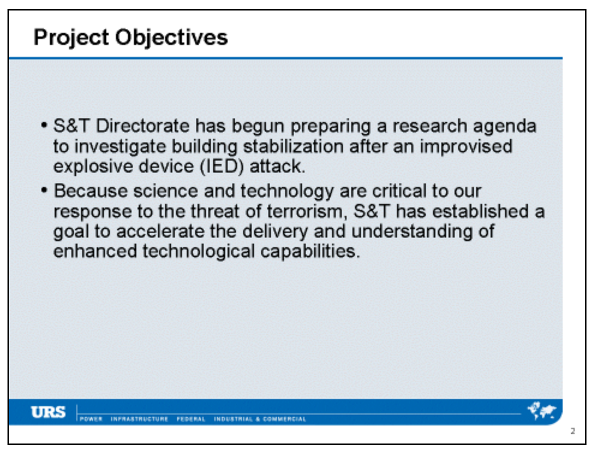
Mr. Letvin holds bachelor's and master's degrees in civil engineering from Syracuse University and received his Juris Doctor from the University of Maryland.

Building Stabilization: An Integrated Approach

This presentation provides an overview of the S&T Stabilization of Buildings project. A brief description and review of the workshop is presented.

Presentation Slides





Workplan - 1

- Initial workshop at ERDC, August 2009 to help in preparing workplan
- Current workplan includes
  - Establishment of several committees
  - Two workshops
    - Monitoring and Sensing
    - First Responders

Workplan - 2

- Other project Tasks
  - Development of Rapid-Screening Post Event Tool
  - BIM Database
  - Testing of Materials and Deployable Systems
  - Outreach Efforts

Committees

- Oversight of Entire Project (Review Committee)
  - U of Mississippi, ERDC, FEMA US&R (Holly Stone)
  - Dr. Robert Hall
  - Dr. Mohammed Ettouney
  - Tate Jackson - coordination

Workshop at ERDC August - 2009

- Held initial Stabilization of Buildings after an IED Attack workshop in August 2009 at the US Army Corps Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi.
- The agenda identified:
  - A list of research priorities and information gaps
  - Information through current data and literature
  - Potential tools, materials, and systems leading to the stabilization of buildings
  - Areas of collaboration and funding sources
  - Sector involvement and commercialization

Monitoring and Sensing Workshop Objectives-1

- State of the art and knowledge gaps in monitoring and sensing technologies.
  - Monitoring and sensing technologies currently available to collect, analyze, and disseminate information on site.
  - Monitoring and sensing technologies currently under development that could be useful to emergency management personnel.
  - Current state of practice for remote versus on-site sensing technologies.

Monitoring and Sensing Workshop Objectives - 2

- Information needed by emergency management personnel.
  - Type and priority of information needed.
  - Form in which emergency management personnel need information transmitted.
  - Information that would cause emergency management personnel to suspend or discontinue a rescue or stabilization effort.
  - Role of uncertainty in real-time decision-making.
  - Method by which information is communicated to the structural engineer and other stakeholders.

Monitoring and Sensing Workshop Objectives - 3

- Monitoring and sensing technologies that need to be developed to better process information.
  - Ways to identify type of data that needs to be monitored and conveyed.
  - Damage identification methods of near-collapse buildings.
  - Structural identification/analysis methods of near-collapse buildings.
- Pre-event versus post-event sensors (deployed by emergency management personnel and the Federal Emergency Management Agency [FEMA] Urban Search & Rescue [US&R] personnel).

First Responders Workshop College Station TX April, 2010

- Near-Collapse Buildings Workshop for Emergency Management Personnel - April 28–29, 2010
- Texas Engineering Extension Service's (TEEX) Disaster City®, College Station, Texas
- The objective of this conference is to investigate the on-site needs and concerns of emergency management personnel.
- A clear understanding of emergency management personnel needs will help facilitate research and development of state-of-the-art technologies and methods to stabilize structures after an IED attack.

First Responders Workshop Objectives - 2

- State-of-the-art building stabilization technologies for emergency management personnel (e.g., shoring, sensing, monitoring, victim/void identification technologies).
- Knowledge gaps and future needs in building stabilization technologies.
- Current research into building stabilization technologies
- Real-time, on-site coordination and information sharing between engineers and emergency management personnel.
- How new and evolving building construction technologies affect future search and rescue activities.

Rapid-Screening Post-Event Tool

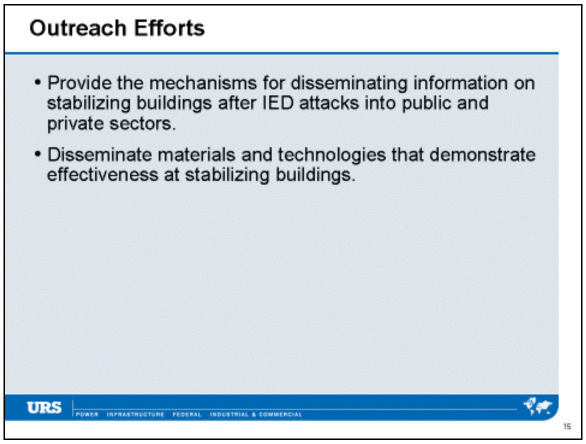
- Development of tools that could take the form of a checklist and will include pertinent building components.
- These two tools will be
  - Simple tool that is suitable for use by first responders in the field,
  - More comprehensive tool that can be used by technical personnel (engineers, architects, etc.).

Database and BIM

- Compete a database that can be of use by stakeholders of the building stabilization community.
- The purpose of the database is to provide different essential information about the subject matter in an organized and comprehensive fashion.
- This database will help decision makers in increasing efficiency, thus saving costs and increasing the security and safety of the officials and the general public.

Testing of Materials and Deployable Systems

- Conduct up to 9 (nine) product test simulations based on preliminary computer and small scale lab evaluations of repaired structure elements (e.g., columns and connections).
- These test simulations will include testing protocols that will be approved by DHS prior to their delivery.
- The selection of products will receive input from the prior research agenda produced from the review committee and the Stabilization Database.


Outreach Efforts
• Provide the mechanisms for disseminating information on stabilizing buildings after IED attacks into public and private sectors.
• Disseminate materials and technologies that demonstrate effectiveness at stabilizing buildings.
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POWER INFRASTRUCTURE FEDERAL INDUSTRIAL & COMMERCIAL
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SESSION 2

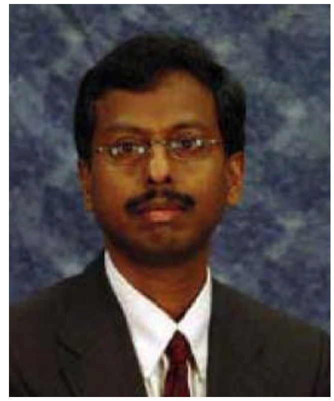
OVERVIEW OF INFORMATION NEEDS

Mohammed Ettouney

Mohammed M. Ettouney, Ph.D., P.E., F. AEI is a Principal at Weidlinger Associates, Inc. The Inventors Hall of Fame recently awarded Dr. Mohammed Ettouney the inventors' award, after he was nominated to receive such a great honor by the American Society of Civil Engineers (ASCE). He was also awarded the Homer Gage Balcom life achievement award by the MET section of ASCE (2008). He also has just won the Project of the Year Award, Platinum Award (2008) for the "New Haven Coliseum Demolition Project" (ACEC, NY). He is a fellow of Architecture Engineering Institute (AEI). Among other recent achievements are the pioneering work on "Theory of Multi-hazards of Infrastructures." "Theory of Progressive Collapse" (DoD), risk Model for Building Security Council (BSC) rating system and innovative green design method for protecting utilities from demolition / blasting (City of New Haven). He has professional interest in diverse areas of structural engineering as demonstrated through the list of his publications, invited presentations, seminars and sessions organized during national/international conferences and his membership in different professional organizations.

Dr. Ettouney has been with Weidlinger Associates since 1984. He received his Doctor of Science degree in Structural Mechanics from the Massachusetts Institute of Technology (MIT), Cambridge, MA, in 1976. Since then, his interests in the structural engineering profession were both as a practitioner and researcher in multi-hazards safety of structures, probabilistic Modeling of Progressive Collapse of Buildings and uncertainties in structural stability, and blast mitigation of numerous buildings around the world; innovative concepts such as "Probabilistic Boundary Element Method," "Scale Independent Elements," and "Framework for evaluation of Lunar Base Structural Concepts". He is a past president and member of board of governs of AEI, member of Board of Directors of the BSC, member of numerous technical committees in the fields of building/infrastructures security, earthquake hazards, architectural engineering Non-Destructive Testing and Structural Health Monitoring. He was the chair of AEI National Conference, 2006, and 2008. He has published more than 325 publications and reports, and has contributed to several books. He introduced numerous new practical and theoretical methods in the fields of earthquake engineering, acoustics, structural health monitoring, progressive collapse, blast engineering, and underwater vibrations. He has co-invented "Seismic-Blast" slotted connection. More recently, he introduced "Economic Theory of Inspection," "General and Special Theories of Instrumentation" and numerous principles and techniques in the field of infrastructures health: they are all pioneering efforts that can help in developing durable infrastructures at reasonable costs. He is coauthoring an upcoming book titled, "*Infrastructures Health in Civil Engineering*," CRC Press, 2009. The book is already being described as a breakthrough and original in the field of infrastructure health and preservation.

Sreenivas Alampalli



Dr. Sreenivas Alampalli is the Director of the Bridge Evaluation Services Bureau at the New York State Department of Transportation (NYSDOT). His responsibilities include managing bridge inspection, inventory, and safety assurance programs at the NYSDOT. His Bureau provides data collection and evaluation services to facilitate the preservation, structural integrity, and safety of more than 17,000 highway bridge infrastructures in New York State. He also has extensive experience in structural engineering research. Dr. Alampalli obtained his Ph.D. and MBA from Rensselaer Polytechnic Institute, his M.S. from Indian Institute of Technology (IIT), Kharagpur, India, and his 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 co-developed the theory of multihazards and has been a great proponent of integrating all vulnerabilities including security for effective infrastructure management. Dr. Alampalli is a Fellow of the American Society of Civil Engineers (ASCE), the American Society for Nondestructive Testing (ASNT), and the International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII). He authored and co-authored more than 250 technical publications. Dr. Alampalli is an active member of several technical committees in the Transportation Research Board (TRB), ASCE, and ASNT; and currently chairs the ASCE Technical Committee on Bridge Management, Inspection, and Rehabilitation. He also recently chaired ASCE/Structural Engineering Institute (SEI)-American Association of State Highway Transportation Officials (AASHTO) ad hoc group on Bridge Inspection, Rating, Rehabilitation, and Replacement, which produced a white paper on bridge inspection and rating in August 2008. He is currently an Associate Editor of the ASCE Journal of Bridge Engineering and also on the editorial board of the Journal of "Structure and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance." He is the Chair of the external expert group formed to advise the Long-Term Bridge Performance Program (LTBPP) initiated by the Federal Highway Administration (FHWA) last year. Awards he received include the Charles Pankow Award for Innovation, awarded by the Civil Engineering Research Foundation (2000); Herbert Howard Government Civil Engineer of the Year Award from ASCE Met Section (2009); and ASNT Mentoring Award (2009).

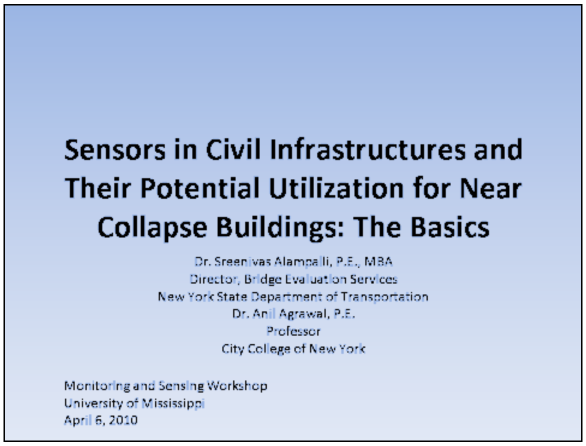
Sensors in Civil Infrastructures and Their Potential Utilization for Near-Collapse Buildings: The Basics

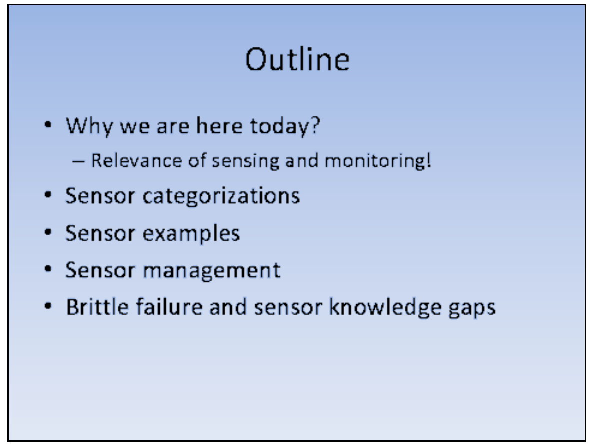
This presentation focused on the relevance of sensing technology to the stabilization of near-collapse buildings. Varying categorizations of sensors were discussed, and examples of existing and state-of-the-art sensors were provided. The presentation concluded with a discussion of how to sense brittle failure, and the direction of future research to close the knowledge gaps regarding prediction of brittle failure.

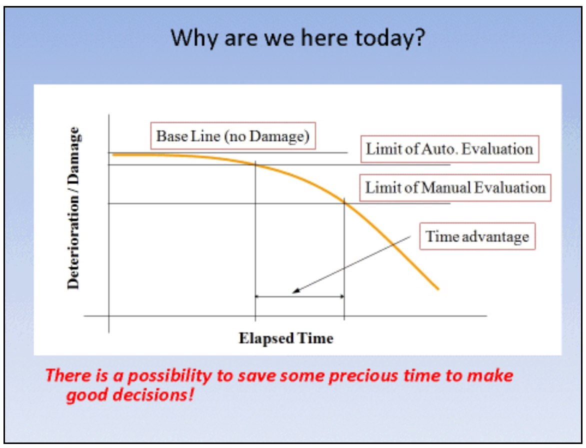
SESSION 2

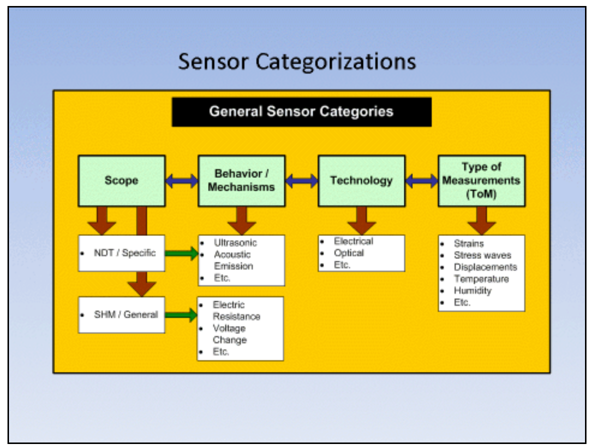
OVERVIEW OF INFORMATION NEEDS

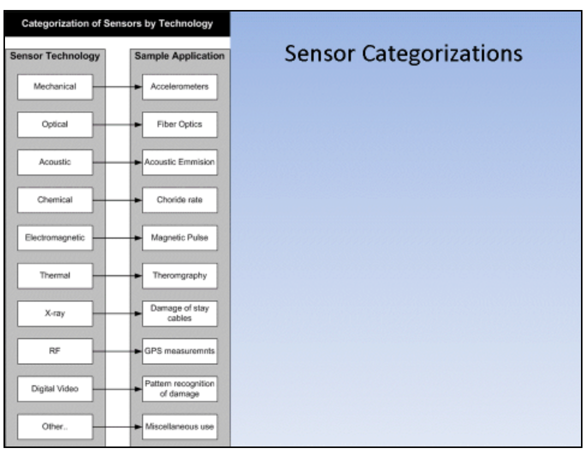
Presentation Slides

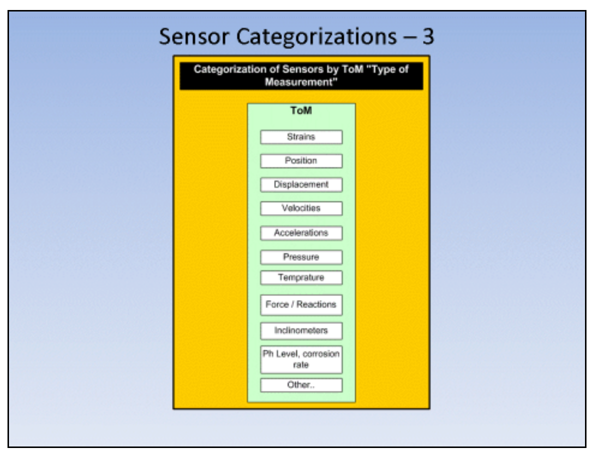








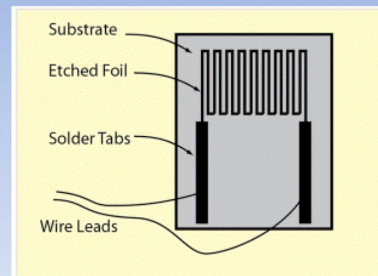




Sensor Examples

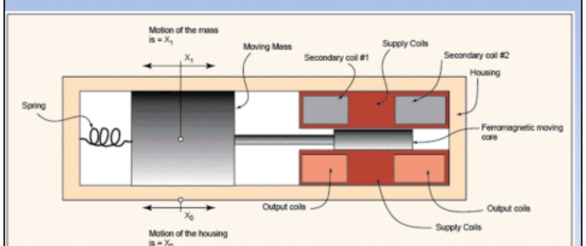
- Strain Sensing
- Acceleration (motion)
- Fiber Optic Sensing
- Thermography
- Laser

Strain Sensors



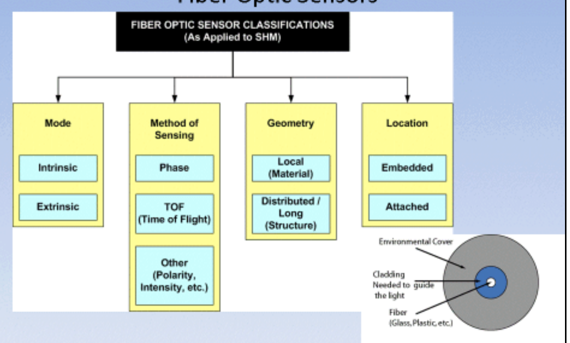
Foil Strain Gauge

Measuring Accelerations



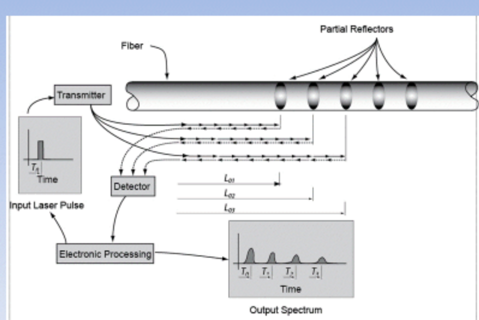
LVDT Accelerometer

Fiber Optic Sensors



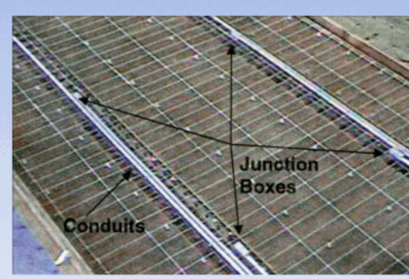
Basic Cross-Section of Fiber Optic Sensor

Fiber Optic Sensors

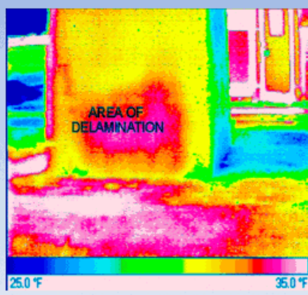


Fiber Optic Sensor: Optical Time Domain Reflectometry (OTDR)

Fiber Optic Sensors



Thermography



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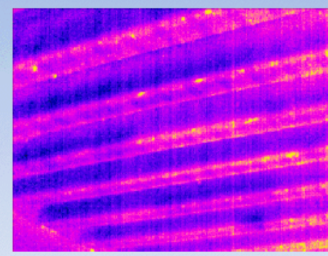
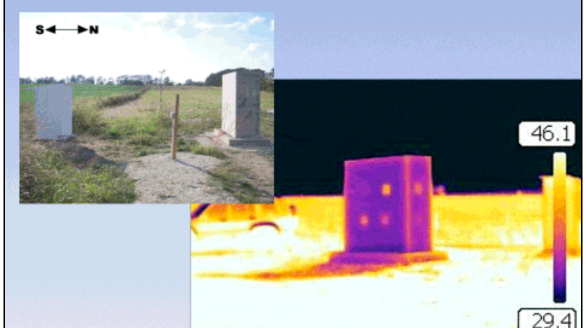
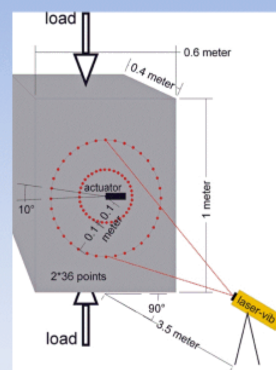


Thermography

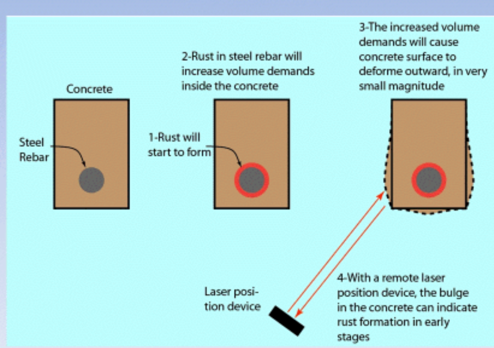


Courtesy: Prof. Glenn Washer

Laser Sensing

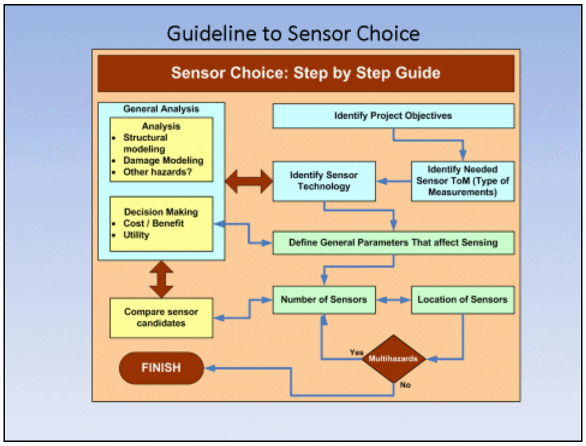


Laser Sensing

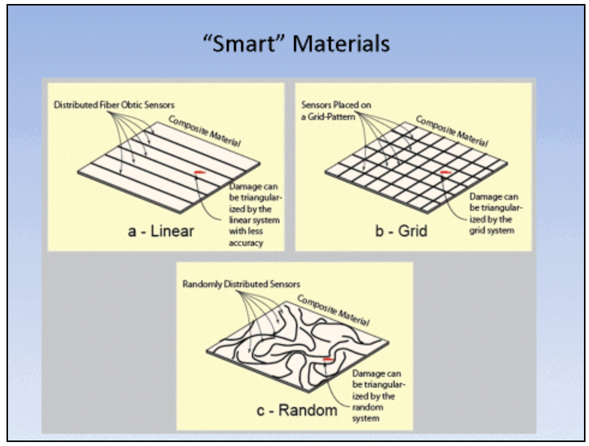


Sensor Management

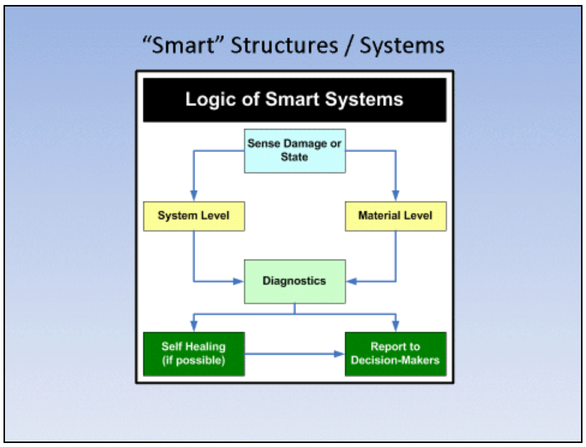
- What is the purpose?
- What decision has to be made?
- Time frame
  - Guideline to sensor choices
  - Smart materials
  - Smart systems
  - Number of sensors
  - Wired vs. wireless sensors
  - Remote sensing



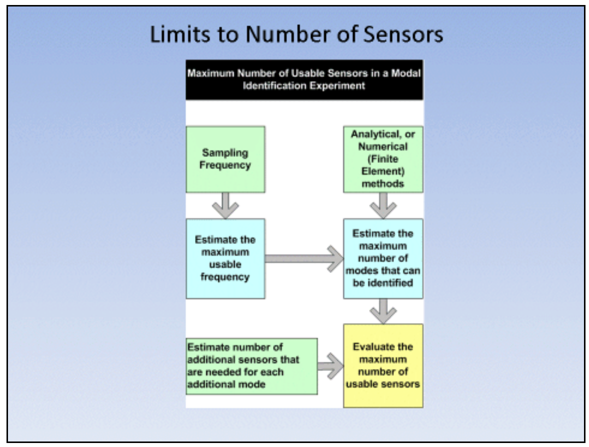
Guideline to Sensor Choice
Sensor Choice: Step by Step Guide
General Analysis
Analysis
Structural modeling
Damage Modeling
Other hazards?
Decision Making
Cost / Benefit
Utility
Identify Project Objectives
Identify Sensor Technology
Identify Needed Sensor ToM (Type of Measurements)
Define General Parameters That affect Sensing
Number of Sensors
Location of Sensors
Compare sensor candidates
Yes
Multihazards
No
FINISH



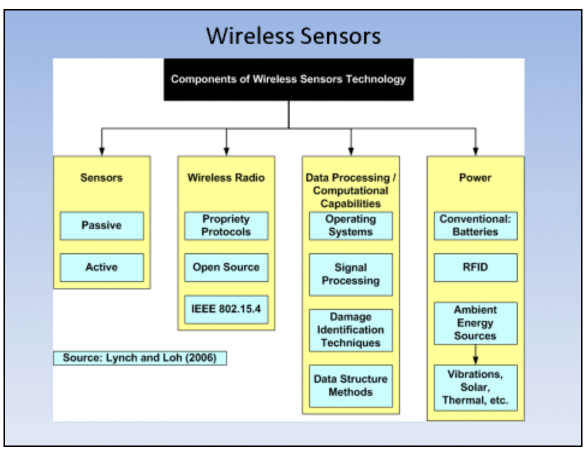
"Smart" Materials
Distributed Fiber Obtic Sensors
Composite Material
Damage can be triangular-ized by the linear system with less accuracy
a - Linear
Sensors Placed on a Grid-Pattern
Composite Material
Damage can be triangular-ized by the grid system
b - Grid
Randomly Distributed Sensors
Composite Material
Damage can be triangular-ized by the random system
c - Random



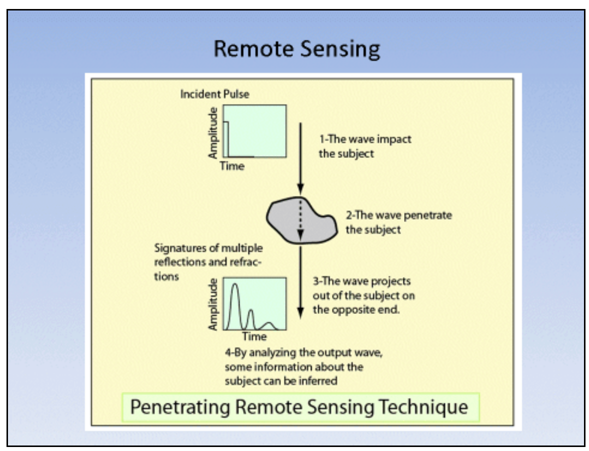
"Smart" Structures / Systems
Logic of Smart Systems
Sense Damage or State
System Level
Material Level
Diagnostics
Self Healing (if possible)
Report to Decision-Makers



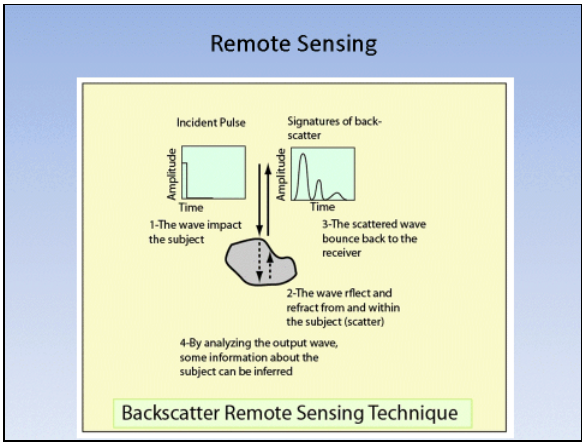
Limits to Number of Sensors
Maximum Number of Usable Sensors in a Modal Identification Experiment
Sampling Frequency
Analytical, or Numerical (Finite Element) methods
Estimate the maximum usable frequency
Estimate the maximum number of modes that can be identified
Estimate number of additional sensors that are needed for each additional mode
Evaluate the maximum number of usable sensors



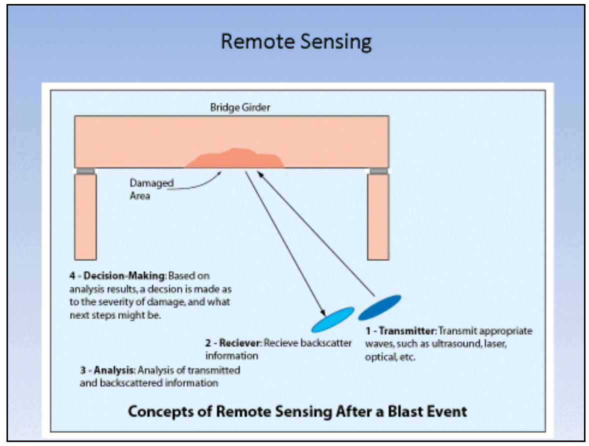
Wireless Sensors
Components of Wireless Sensors Technology
Sensors
Passive
Active
Wireless Radio
Propriety Protocols
Open Source
IEEE 802.15.4
Data Processing / Computational Capabilities
Operating Systems
Signal Processing
Damage Identification Techniques
Data Structure Methods
Power
Conventional: Batteries
RFID
Ambient Energy Sources
Vibrations, Solar, Thermal, etc.
Source: Lynch and Loh (2006)



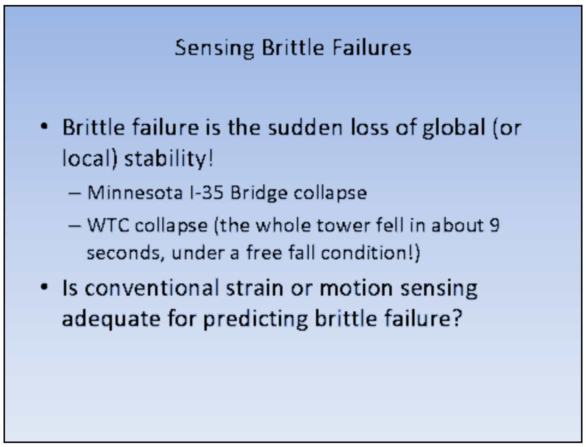
Remote Sensing
Incident Pulse
Amplitude
Time
1-The wave impact the subject
2-The wave penetrate the subject
Signatures of multiple reflections and refrac-tions
3-The wave projects out of the subject on the opposite end.
4-By analyzing the output wave, some information about the subject can be inferred
Penetrating Remote Sensing Technique



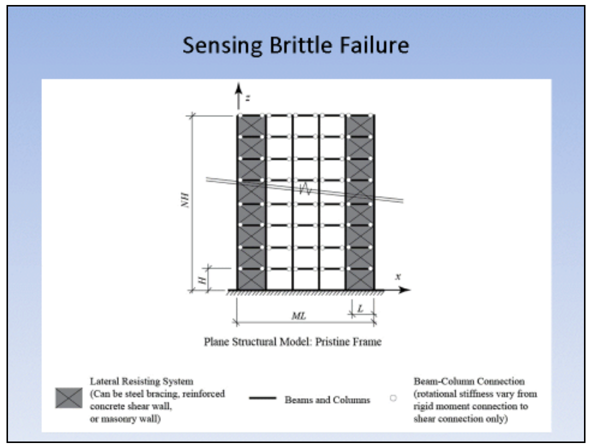
Remote Sensing
Incident Pulse
Signatures of back-scatter
Amplitude
Time
Amplitude
Time
1-The wave impact the subject
3-The scattered wave bounce back to the receiver
2-The wave rflect and refract from and within the subject (scatter)
4-By analyzing the output wave, some information about the subject can be inferred
Backscatter Remote Sensing Technique



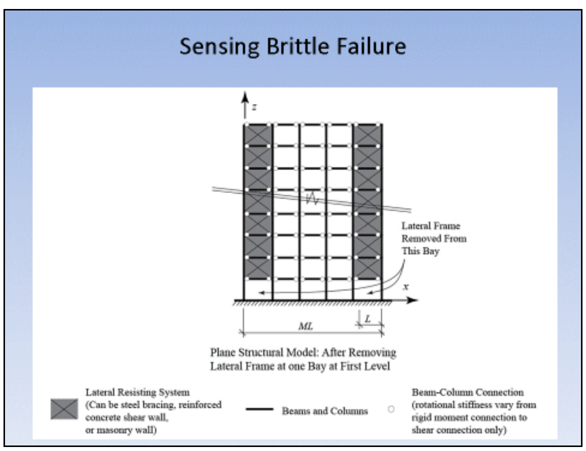
Remote Sensing
Bridge Girder
Damaged Area
4 - Decision-Making: Based on analysis results, a decsion is made as to the severity of damage, and what next steps might be.
1 - Transmitter: Transmit appropriate waves, such as ultrasound, laser, optical, etc.
2 - Reciever: Recieve backscatter information
3 - Analysis: Analysis of transmitted and backscattered information
Concepts of Remote Sensing After a Blast Event



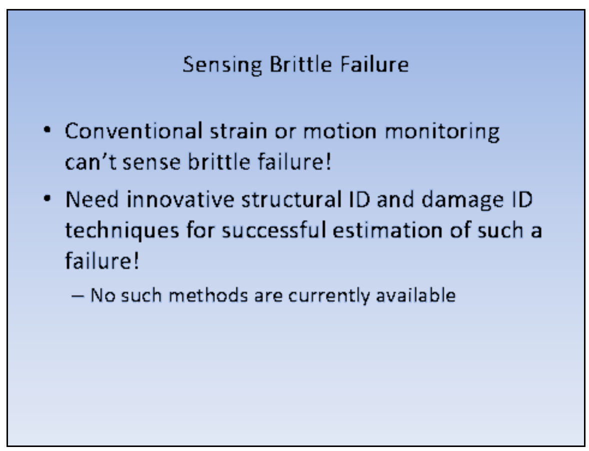
Sensing Brittle Failures
• Brittle failure is the sudden loss of global (or local) stability!
– Minnesota I-35 Bridge collapse
– WTC collapse (the whole tower fell in about 9 seconds, under a free fall condition!)
• Is conventional strain or motion sensing adequate for predicting brittle failure?



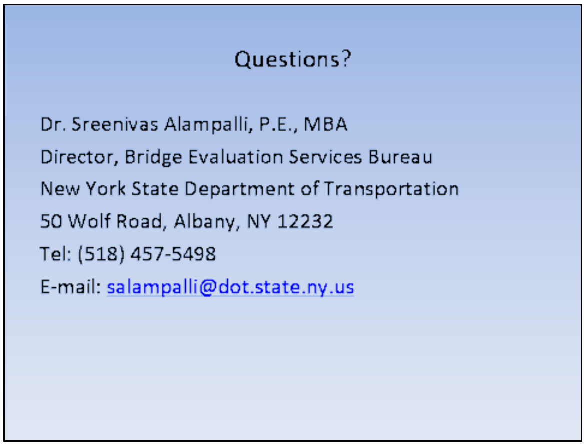
Sensing Brittle Failure
z
NH
H
x
ML
L
Plane Structural Model: Pristine Frame
Lateral Resisting System (Can be steel bracing, reinforced concrete shear wall, or masonry wall)
Beams and Columns
Beam-Column Connection (rotational stiffness vary from rigid moment connection to shear connection only)



Sensing Brittle Failure
z
Lateral Frame Removed From This Bay
x
ML
L
Plane Structural Model: After Removing Lateral Frame at one Bay at First Level
Lateral Resisting System (Can be steel bracing, reinforced concrete shear wall, or masonry wall)
Beams and Columns
Beam-Column Connection (rotational stiffness vary from rigid moment connection to shear connection only)



Sensing Brittle Failure
• Conventional strain or motion monitoring can't sense brittle failure!
• Need innovative structural ID and damage ID techniques for successful estimation of such a failure!
– No such methods are currently available



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Peter Vanderzee

Mr. Vanderzee holds two engineering degrees: a B.S. in Mechanical Engineering from Rensselaer Polytechnic Institute in Troy, New York and an M. Engr. in Industrial Engineering from Texas A&M University.

Mr. Vanderzee started his working career as a production engineer in the U.S. Army Electronics Command. After several years in R&D, he accepted a position with a Dallas-based energy and mining business. He held a variety of management positions over the next 10 years; including oil trading, project management and corporate strategic planning. He next joined a venture funded environmental start-up, being named President and CEO after two years. With two subsequent employers he held executive positions in construction services, sales, business development and corporate administration in both Houston and Atlanta.

In 2000, Mr. Vanderzee started a consulting business focused on technology commercialization, called Launch-Right. He also founded Transparent Solutions to commercialize a contractor risk rating technology. His first consulting client, LifeSpan Technologies, eventually asked him to lead the firm as it developed and launched a commercialization program for its patented structural monitoring technology. Mr. Vanderzee has led the development of LifeSpan's business while helping to define the most appropriate use of structural monitoring technology in this emerging market. He has authored over 10 publications and White Papers, while making well over 100 presentations to structure owners, engineering consultants, regulatory agencies, and political groups.

Adopting Commercially Available Sensing and Monitoring Technologies

DHS has expressed concern about the availability and affordability of sensing and monitoring technologies for buildings considered susceptible to IED attack. Of particular concern is the availability of near real-time, objective, structural integrity data that can guide post-event decision makers to enter, or not enter, a building (or any other structure) after an IED attack, for purposes of in-depth structural investigation. Two examples of an IED attack which may have compromised structural integrity include the Murrah Federal Building in Oklahoma City in 1995 and the first World Trade Center bombing in 1993.

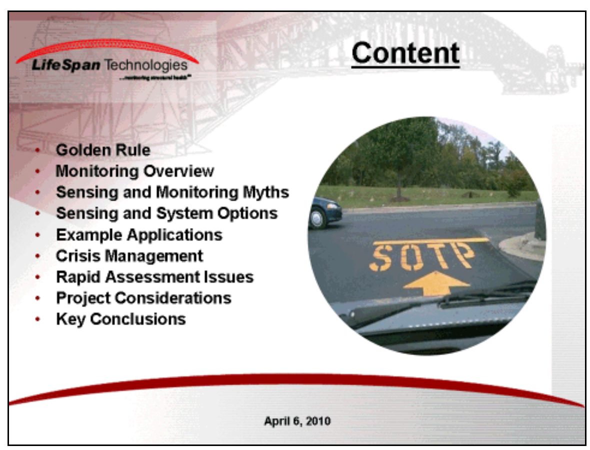
Due to the recent vintage of IED threats, older buildings subject to terrorist interest were not designed or armored to mitigate structural damage against IED attack. Consequently, their structural integrity can be easily compromised by blast forces that were not considered in original design and construction. In addition, while some buildings have subsequently been armored, the nature (size and location) of an IED attack remains so random that adequate structural analysis and mitigation efficacy remain more a factor of luck than objective determination a priori.

This paper and accompanying presentation explain why a range of structural monitoring technologies were developed and commercialized over the past 10 years and whether these commercial technologies can be confidently adopted and encouraged by DHS to assure personal safety when first responders, medical evacuation, law enforcement, and structural engineers enter partially destroyed buildings to meet their mission requirements.

Particular emphasis is placed on identifying a variety of commercially available sensing and monitoring technologies, how those technologies compare one to another, especially in terms of blast resistance and relative cost, and lessons learned by using these technologies on bridges and other structures for at least the past 5 years.

This presentation is non-commercial in nature, reflecting the workshop emphasis on determining whether a major R&D program is required to develop IED-specific sensing devices and monitoring solutions, or if commercially available technologies and solutions are adequate to meet the intended need.

Presentation Slides



LifeSpan Technologies

The Golden Rule of Monitoring

$$RELIABILITY = (COMPLEXITY)^{-1}$$

April 6, 2010

LifeSpan Technologies

Monitoring Overview

- **History**
  - Roots in academia
  - Focus on data intensity
  - Sensor development
  - System integration
  - Europe and Asia first
  - Initial interest in large, signature bridges
- **Current Status**
  - Bevy of niche firms
  - Technology is proven
  - Applications broadening
  - Integrated analytics
  - Adoption rate is the commercial challenge
  - Focus on financial return

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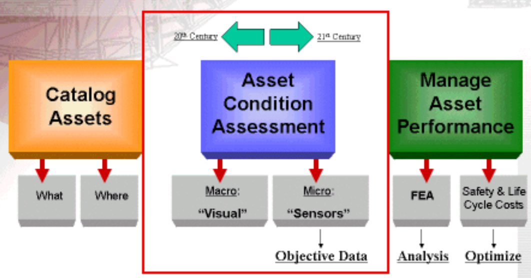
Where Does Monitoring Fit?



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Why Isn't Visual Inspection Sufficient?

- Visual condition ratings varied by +/- 2 states from the mean in a 2000 FHWA study. (1)
- "This methodology is highly subjective and produces variable results." (2)
- "Visual inspection also does not capture hidden deterioration or damage." (3)

1. *Reliability of Visual Inspection*, Public Roads Magazine, March/April 2001
2. *Condition Assessment of Highway Structures, Past, Present and Future*, TR Circular E-C104
3. IBID

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Sensing and Monitoring Myths

- Monitoring is expensive and complicated.
- Monitoring is only needed to warn of impending failure.
- Sensors are like antibiotics when sick – more is better.
- Smaller and smaller strain sensors are better.
- More data is better than less data.
- Power supply is a problem.
- Temperature changes are not important.
- Wireless sensor to sensor nodes better than hard wiring.

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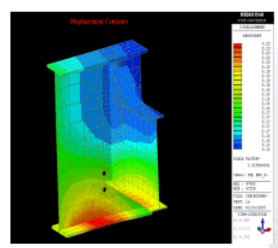
Monitored "Smart Structure" Concept

- Structure participates in managing its condition:
  - Checks strain and other parameters regularly.
  - Monitors known defects continuously.
  - Catalogs symptoms.
  - Communicates distress.
  - Supports definitive diagnosis using monitoring data.



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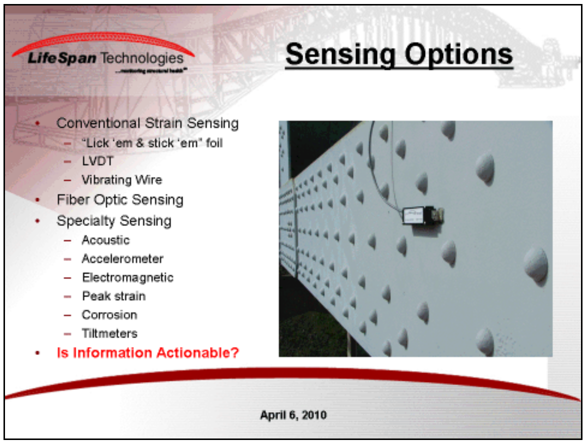

LifeSpan Technologies
Sensing Options
Conventional Strain Sensing
"Lick 'em & stick 'em" foil
LVDT
Vibrating Wire
Fiber Optic Sensing
Specialty Sensing
Acoustic
Accelerometer
Electromagnetic
Peak strain
Corrosion
Tiltmeters
Is Information Actionable?
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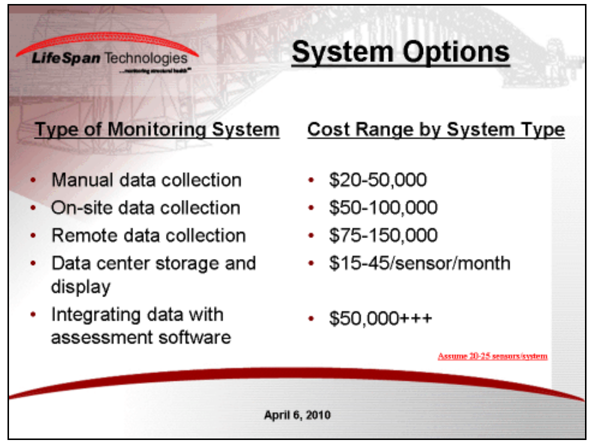

LifeSpan Technologies
System Options
Type of Monitoring System
Cost Range by System Type
Manual data collection
$20-50,000
On-site data collection
$50-100,000
Remote data collection
$75-150,000
Data center storage and display
$15-45/sensor/month
Integrating data with assessment software
$50,000+++
Assume 20-25 sensors/system
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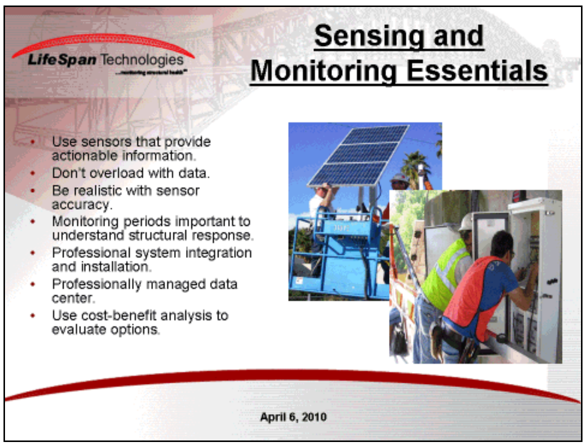

LifeSpan Technologies
Sensing and Monitoring Essentials
Use sensors that provide actionable information.
Don't overload with data.
Be realistic with sensor accuracy.
Monitoring periods important to understand structural response.
Professional system integration and installation.
Professionally managed data center.
Use cost-benefit analysis to evaluate options.
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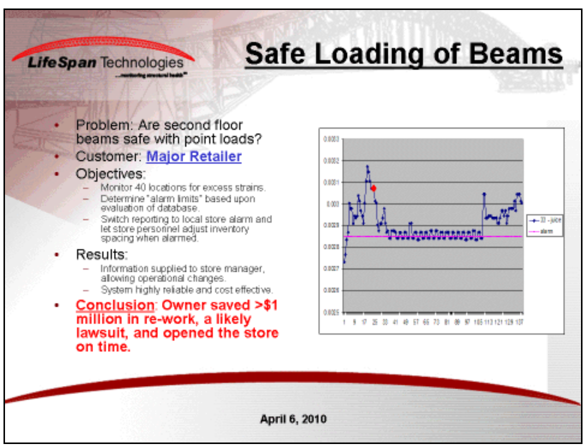
LifeSpan Technologies
Example Applications



LifeSpan Technologies
Safe Loading of Beams
Problem: Are second floor beams safe with point loads?
Customer: Major Retailer
Objectives:
Monitor 40 locations for excess strains.
Determine "alarm limits" based upon evaluation of database.
Switch reporting to local store alarm and let store personnel adjust inventory spacing when alarmed.
Results:
Information supplied to store manager, allowing operational changes.
System highly reliable and cost effective.
Conclusion: Owner saved >$1 million in re-work, a likely lawsuit, and opened the store on time.
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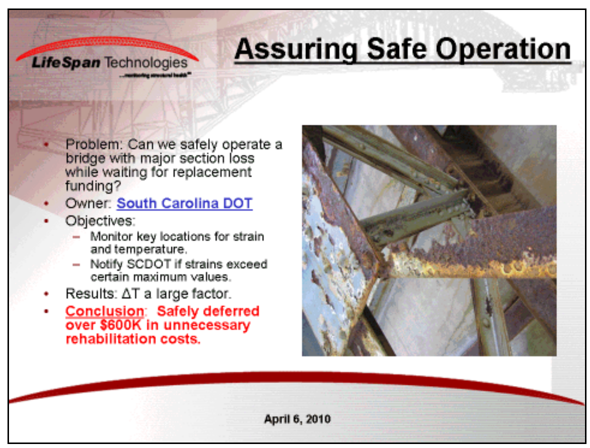

LifeSpan Technologies
Assuring Safe Operation
Problem: Can we safely operate a bridge with major section loss while waiting for replacement funding?
Owner: South Carolina DOT
Objectives:
Monitor key locations for strain and temperature.
Notify SCDOT if strains exceed certain maximum values.
Results: ΔT a large factor.
Conclusion: Safely deferred over $600K in unnecessary rehabilitation costs.
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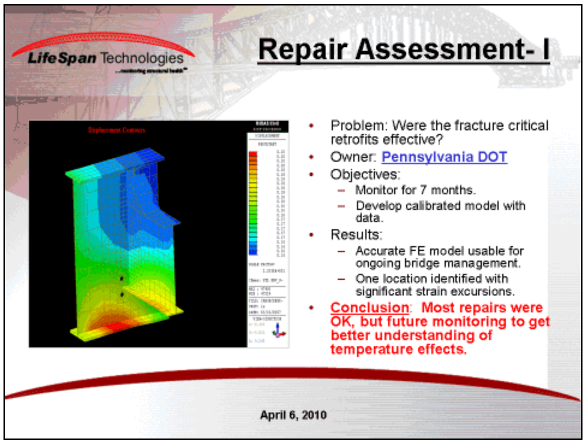
LifeSpan Technologies
Repair Assessment- I
Problem: Were the fracture critical retrofits effective?
Owner: Pennsylvania DOT
Objectives:
– Monitor for 7 months.
– Develop calibrated model with data.
Results:
– Accurate FE model usable for ongoing bridge management.
– One location identified with significant strain excursions.
Conclusion: Most repairs were OK, but future monitoring to get better understanding of temperature effects.
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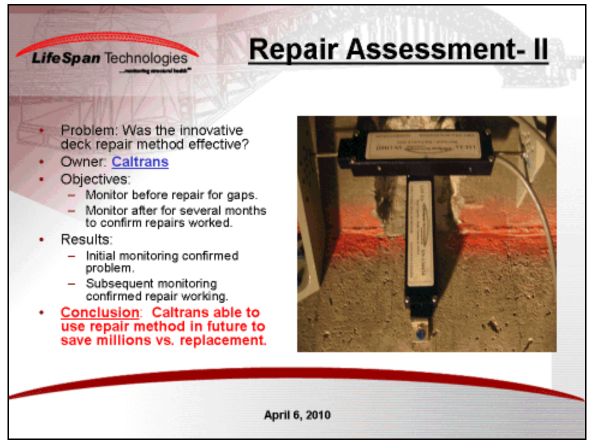
LifeSpan Technologies
Repair Assessment- II
Problem: Was the innovative deck repair method effective?
Owner: Caltrans
Objectives:
– Monitor before repair for gaps.
– Monitor after for several months to confirm repairs worked.
Results:
– Initial monitoring confirmed problem.
– Subsequent monitoring confirmed repair working.
Conclusion: Caltrans able to use repair method in future to save millions vs. replacement.
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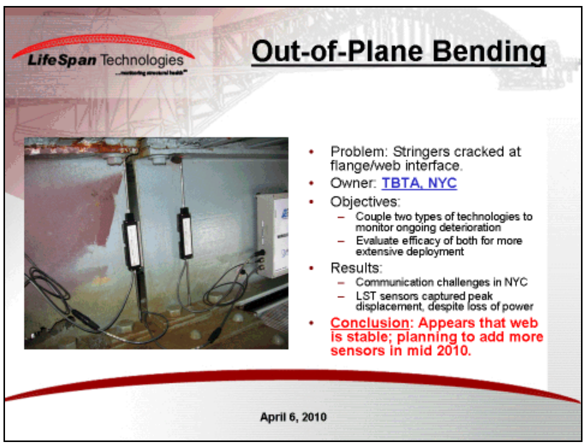
LifeSpan Technologies
Out-of-Plane Bending
Problem: Stringers cracked at flange/web interface.
Owner: TBTA, NYC
Objectives:
– Couple two types of technologies to monitor ongoing deterioration
– Evaluate efficacy of both for more extensive deployment
Results:
– Communication challenges in NYC
– LST sensors captured peak displacement, despite loss of power
Conclusion: Appears that web is stable; planning to add more sensors in mid 2010.
April 6, 2010


LifeSpan Technologies
Damage Monitoring
Problem: Potential damage from adjacent construction.
Customer: City of Raleigh, N.C.
Objectives:
– Monitor adjacent construction effects on new parking deck.
– Pinpoint damage when it occurs.
– Notify engineer (and insurer) when movement (damage) is detected.
Results:
– Owner's engineer followed construction activity.
– Owner's engineer alerted with limit alarms.
– No damage detected.
Conclusion: Deck structure protected at no cost to owner with no lawsuits or loss of revenue from construction damage.
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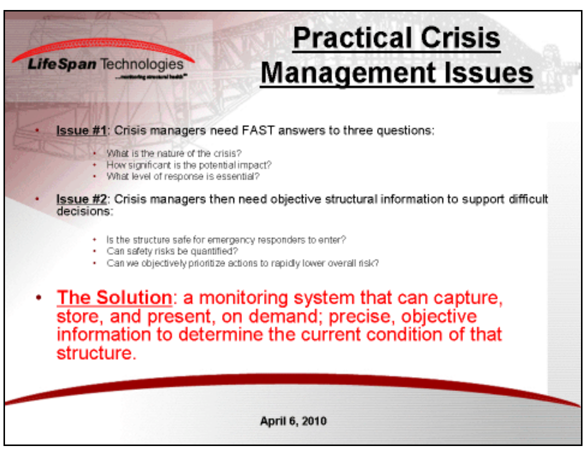
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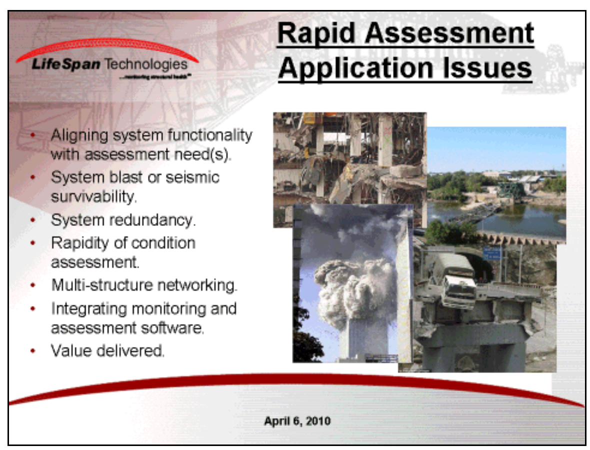
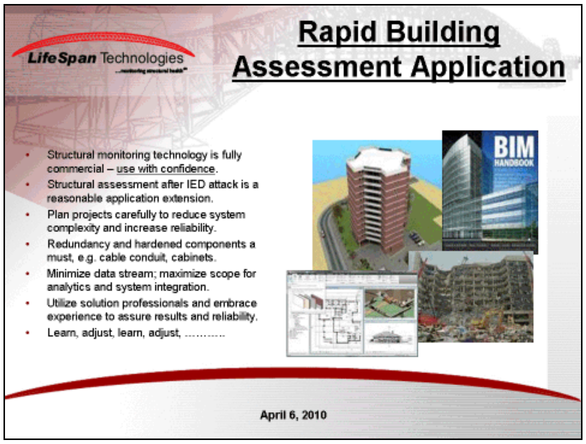
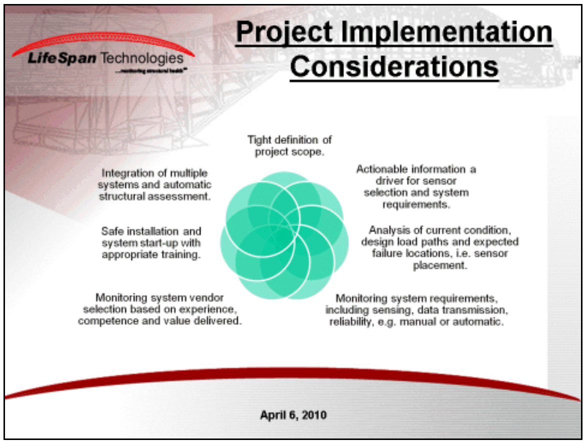
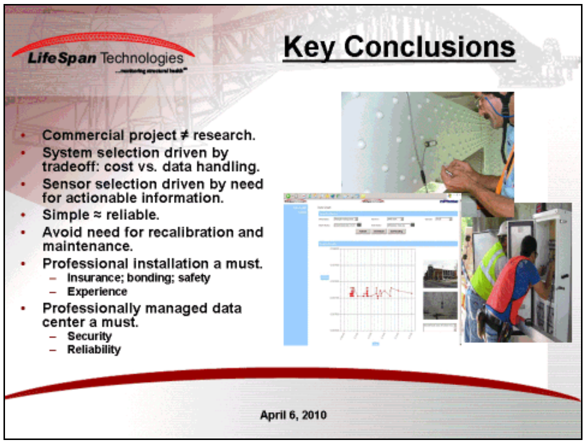
Practical Crisis Management Issues
Issue #1: Crisis managers need FAST answers to three questions:
What is the nature of the crisis?
How significant is the potential impact?
What level of response is essential?
Issue #2: Crisis managers then need objective structural information to support difficult decisions:
Is the structure safe for emergency responders to enter?
Can safety risks be quantified?
Can we objectively prioritize actions to rapidly lower overall risk?
The Solution: a monitoring system that can capture, store, and present, on demand; precise, objective information to determine the current condition of that structure.
April 6, 2010


LifeSpan Technologies
Rapid Assessment Application Issues
Aligning system functionality with assessment need(s).
System blast or seismic survivability.
System redundancy.
Rapidity of condition assessment.
Multi-structure networking.
Integrating monitoring and assessment software.
Value delivered.
April 6, 2010







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Elizabeth Ervin

Dr. Elizabeth K. Ervin joined the Department of Civil Engineering at Ole Miss in August of 2006 as an Assistant Professor. She has two Civil Engineering degrees: a B.S. in cursu honorum with a concentration in structural mechanics from Tennessee Technological University and an M.S. with a concentration in structures from Vanderbilt University. She completed her Doctorate at Carnegie Mellon University in the Department of Mechanical Engineering while working at Bechtel Bettis Atomic Power Laboratory, a Department of Energy and U.S. Navy Contractor. She has also been employed by the Air Force Research Laboratory at Wright-Patterson Air Force Base in Dayton, Ohio, and the Tennessee Department of Transportation in both Memphis and Cookeville, Tennessee. Her research interests are interdisciplinary, linking civil engineering, mechanical engineering, and computer science. Possible topics involve impact of multiple flexible structures, discontinuous State mapping, finite elements, structural integrity, fracture mechanics, and combined dynamic loading. She has been funded by the Office of Naval Research, the Army Research Office, Oak Ridge Associated Universities, the National Science

Foundation, and the U.S. Nuclear Regulatory Commission. Her experience also includes experimentation and laboratory instrumentation. She has built a new facility, the Multi-Function Dynamics Laboratory (MFDL), for the fundamental study of structural components under shock and vibration.

From Sensing to Damage Identification in Unstable Buildings

Identification of Damage Threshold without Pre-Damage Data

Many structural health evaluation issues are currently being explored by researchers all over the globe. This presentation provides an overview of the following key questions:

- What data do we need to capture?
- How to process the data into useful information?
- How do we determine a "dangerous" threshold for any building in real-time?

Several different types of data can currently be captured by sensors both large and small. Gauges of displacement, strain, and acceleration must be attached to the building. Potentially further damaging the structure, an excitation may also need to be applied. The time, location, and ease of sensor installation are also major concerns. Non-contact sensors seem ideal as they are easy to place but are costly. The sensors need some power source; this leads to energy harvesting and radio frequency identification (RFID) tagging. Running uninterrupted cable is also a challenge, so wireless data acquisition appears to be the only solution.

Once data has been acquired, the means of processing it are also in question. The greatest concern is which parameter should be selected as the damage indicator. There are numerous potential choices, and a study is underway at the University of Mississippi to evaluate potential indicators for practicality. Damage alters the structure's stiffness, so the simplest measure would be natural frequency. However, this has been shown as a rather insensitive parameter that does not locate damage. Thus, mode shape shifts can be examined, but sophisticated software is required along with excellent data. The conclusion of most work is that a statistical measure must be applied, but which one? Each individual calculation appears to have its advantages and disadvantages, so a combination of statistical measures may be the answer.

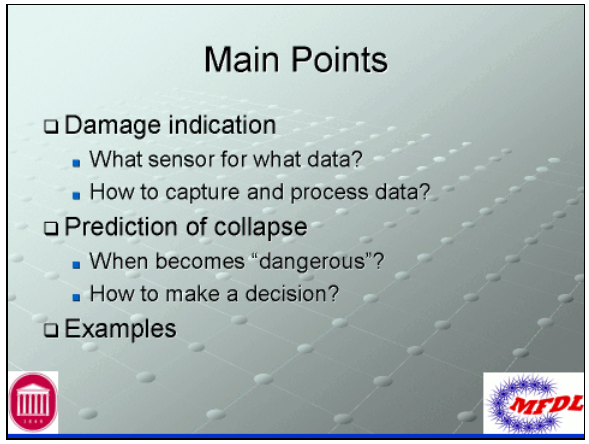
For each of these damage indicators, a threshold must be selected such that risk can be evaluated. A specified number needs to tell a first responder either that it is safe to enter or to exit because the structure is near collapse. This predetermined threshold must be 100% reliable for human safety, but it heavily depends upon data fidelity and indicator sensitivity. It also depends on the type of structure and its pre-damage condition. Each building is unique in its as-built configuration, even with identical plans. Decision-making for one structure can be based upon another structure but only through broad classifications. Thus, a large inventory of different structures needs to be evaluated before algorithm application. Before an attack, high value terrorist targets may have some pre-existing structural monitoring, required for any statistical analysis. However, low value targets are unlikely to have any prior instrumentation, so a means of evaluating the safety of infrastructure after a natural disaster, for example, is also needed. Lastly, this threshold must be measured and a decision made in real-time. This leads to the concept of ambient computing with some artificially intelligent decision-maker.

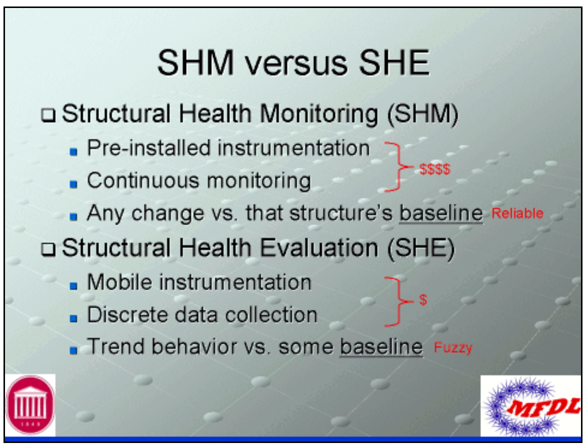
SESSION 2

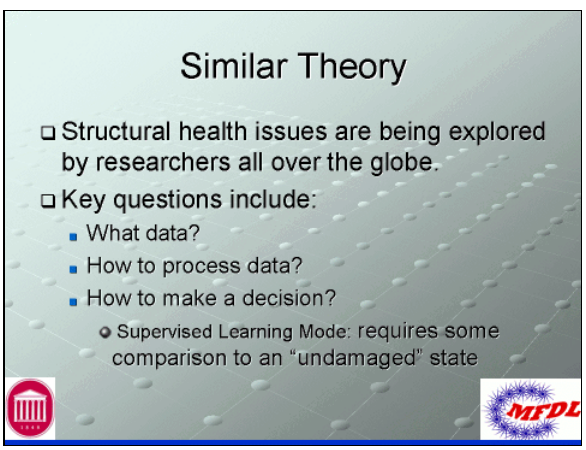
OVERVIEW OF INFORMATION NEEDS

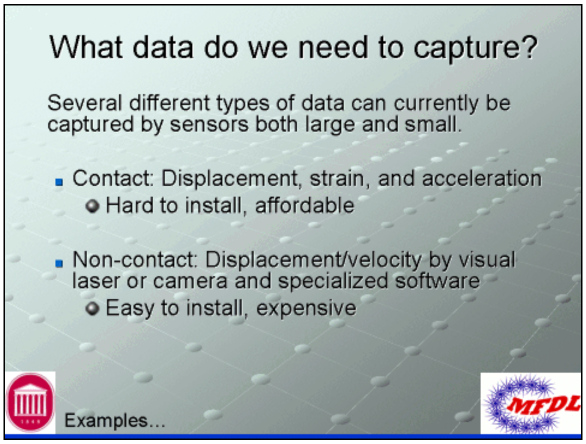
Today it seems that there are more questions than answers, but the goals of structural health evaluation are important. Higher safety level and better infrastructure management will continue to motivate researchers toward answers.

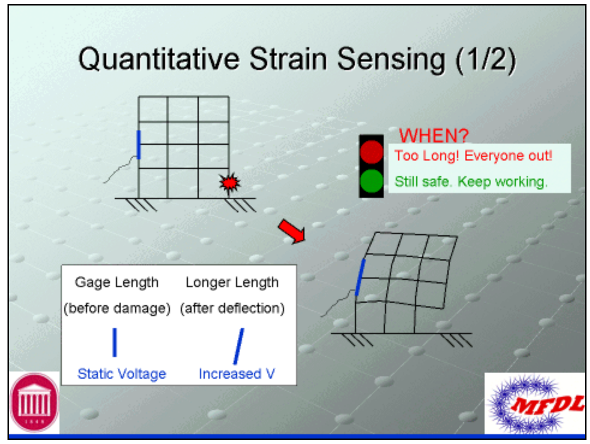
Presentation Slides

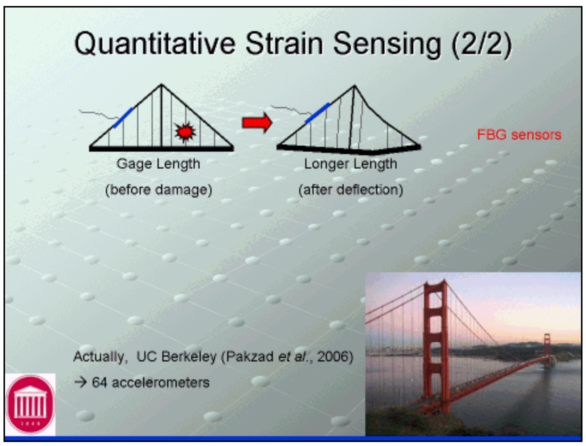


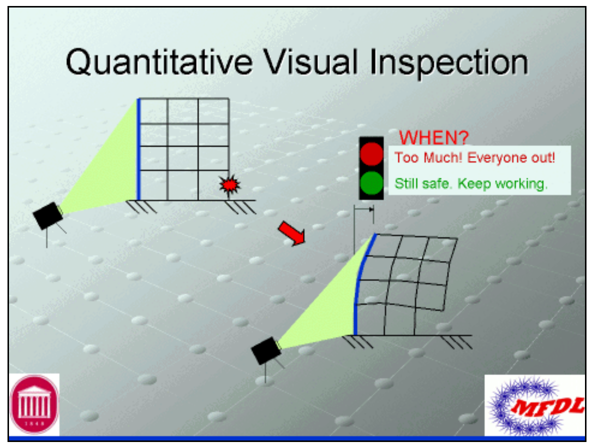


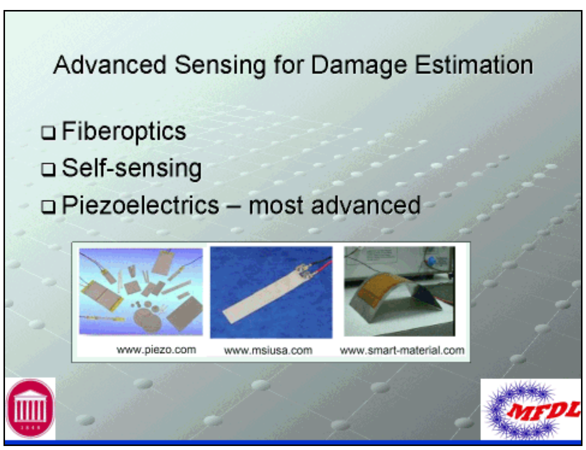


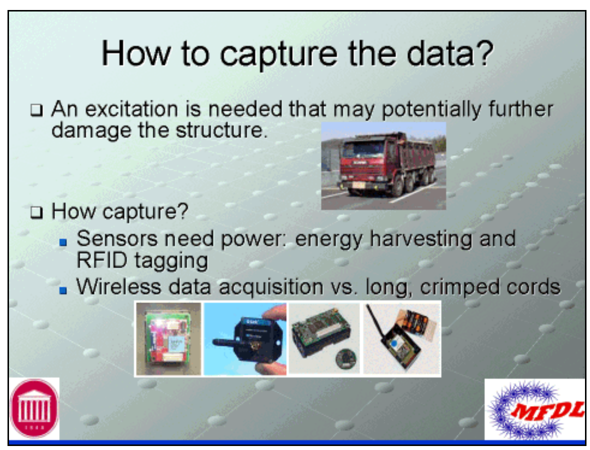

What data do we need to capture?
Several different types of data can currently be captured by sensors both large and small.
Contact: Displacement, strain, and acceleration
Hard to install, affordable
Non-contact: Displacement/velocity by visual laser or camera and specialized software
Easy to install, expensive
Examples…
MFDL

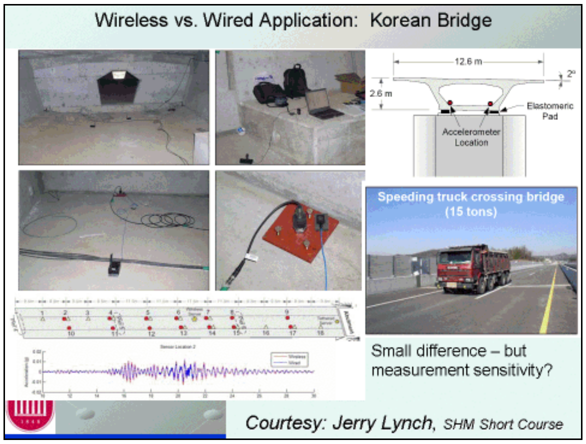

Quantitative Strain Sensing (1/2)
WHEN?
Too Long! Everyone out!
Still safe. Keep working.
Gage Length
(before damage)
Longer Length
(after deflection)
Static Voltage
Increased V
MFDL


Quantitative Strain Sensing (2/2)
Gage Length
(before damage)
Longer Length
(after deflection)
FBG sensors
Actually, UC Berkeley (Pakzad et al., 2006)
→ 64 accelerometers

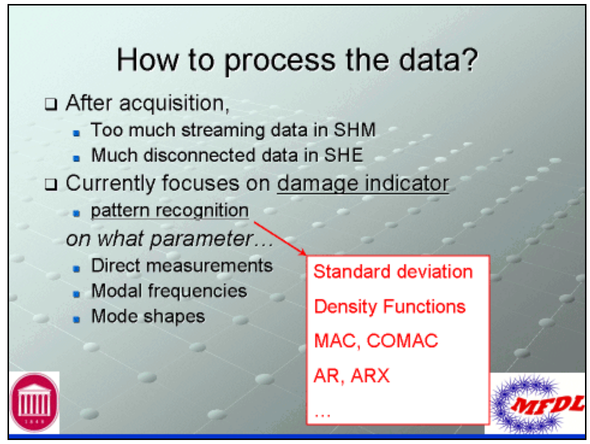

Quantitative Visual Inspection
WHEN?
Too Much! Everyone out!
Still safe. Keep working.
MFDL


Advanced Sensing for Damage Estimation
Fiberoptics
Self-sensing
Piezoelectrics – most advanced
www.piezo.com
www.msiusa.com
www.smart-material.com
MFDL

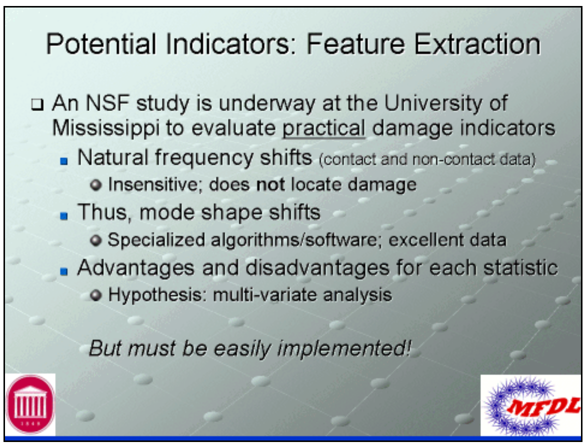

How to capture the data?
An excitation is needed that may potentially further damage the structure.
How capture?
Sensors need power: energy harvesting and RFID tagging
Wireless data acquisition vs. long, crimped cords
MFDL



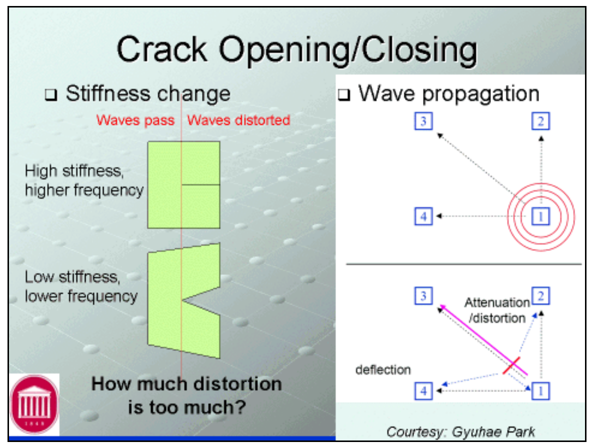
Wireless vs. Wired Application: Korean Bridge
12.6 m
2.6 m
Elastomeric Pad
Accelerometer Location
Speeding truck crossing bridge (15 tons)
Small difference – but measurement sensitivity?
Courtesy: Jerry Lynch, SHM Short Course



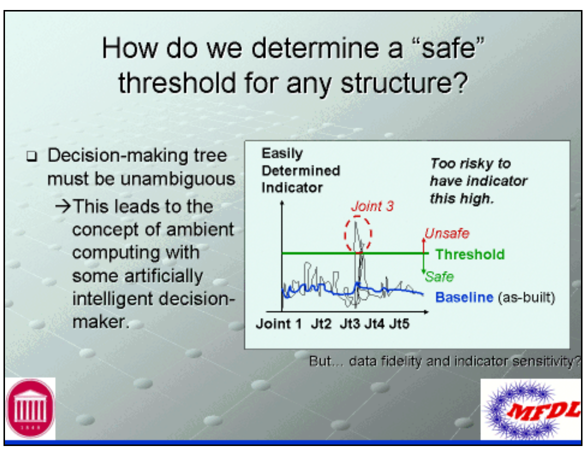
How to process the data?
After acquisition,
Too much streaming data in SHM
Much disconnected data in SHE
Currently focuses on damage indicator
pattern recognition
on what parameter…
Direct measurements
Modal frequencies
Mode shapes
Standard deviation
Density Functions
MAC, COMAC
AR, ARX
…
MFDL



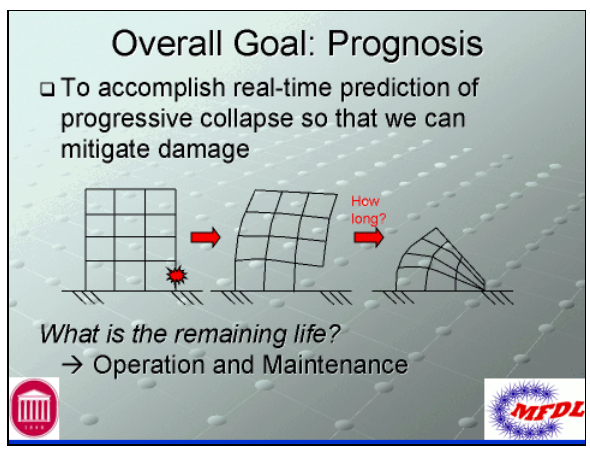
Potential Indicators: Feature Extraction
An NSF study is underway at the University of Mississippi to evaluate practical damage indicators
Natural frequency shifts (contact and non-contact data)
Insensitive; does not locate damage
Thus, mode shape shifts
Specialized algorithms/software; excellent data
Advantages and disadvantages for each statistic
Hypothesis: multi-variate analysis
But must be easily implemented!
MFDL



Crack Opening/Closing
Stiffness change
Waves pass
Waves distorted
High stiffness, higher frequency
Low stiffness, lower frequency
How much distortion is too much?
Wave propagation
3
2
4
1
Attenuation /distortion
deflection
Courtesy: Gyuhae Park

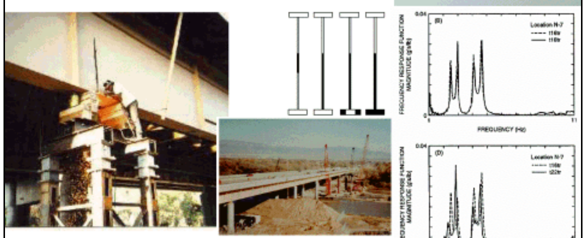


How do we determine a "safe" threshold for any structure?
Decision-making tree must be unambiguous
→This leads to the concept of ambient computing with some artificially intelligent decision-maker.
Easily Determined Indicator
Too risky to have indicator this high.
Joint 3
Unsafe
Threshold
Safe
Baseline (as-built)
Joint 1 Jt2 Jt3 Jt4 Jt5
But… data fidelity and indicator sensitivity?
MFDL



Overall Goal: Prognosis
To accomplish real-time prediction of progressive collapse so that we can mitigate damage
How long?
What is the remaining life?
→ Operation and Maintenance
MFDL

Application: I-40 Bridge Damage



Strain energy method, mode shape curvature, flexibility, uniform flexibility, change in stiffness.

All methods less sensitive (3-6%) than solar heating (up to 26%)

Farrar, C.R., Cornwell, P.J., Doebling, S.W., *et al.*, 2000, "Structural Health Monitoring Studies of the Alamosa Canyon and I-40 Bridges," Los Alamos National Laboratory Report LA-13635-MS.

How get threshold for any building in real-time?

Important and needed capability!

- A first responder : Get out now / Safe to enter
- Instant decision-making for a new structure
  - Based on other structure through broad classification.
  - Need large inventory for **generic baseline**.
- Target Value matters
  - High: some pre-existing structural data/monitoring.
  - Low: unlikely to have any data
    → infrastructure after a disaster?

Consequences Vary

Collaboration

- Civil engineers – structural, geotechnical
- Mechanical engineers – vibrations, acoustic, controls
- Electrical engineers and statisticians – signal processing
- Aerospace engineers – initiators
- Technicians – installation, implementation
- Government agencies – support, enforcement
- ...

What We Know vs. What We Would Like to Know

What We Know

- Greater safety and better infrastructure management motivate research.
- Algorithms show promise for well-behaved specialized systems.
- Pre-damage data is currently required.

What We Would Like to Know

- Cost Effectiveness?
- Response time?
- Maintenance?
- Ease of Use?
- Health when no pre-damage data exists?*

Seems more questions than answers.

Thanks for your attention.

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SESSION 2
OVERVIEW OF INFORMATION NEEDS

Hollice Stone

Hollice Stone, PE, President of Stone Security Engineering, is an experienced Security Engineer, with 18 years of engineering, blast, antiterrorism and emergency response experience. She has devoted her career to helping protect people, buildings, campuses, and critical infrastructure from terrorism. Stone has been instrumental in criteria development, research, and educational initiatives in both the engineering and emergency response communities. Accomplishments include anti-terrorism and security engineering design and assessments of new and existing facilities for the U.S. Departments of State, Justice, Homeland Security, and Defense, National Universities, chemical plants, oil refineries, Fortune 500 companies, and international non-governmental organizations.

Ms. Stone has also been instrumental in bridging the gap between security engineering and more traditional life-safety considerations through her work with FEMA, developing training simulators for widespread structural collapse scenarios, presenting first responder classes on explosion hazards, working with the Fire Department of the City of New York in their development of Emergency Action Plan Director certification examinations in support of Local Law 26, acting as a member of the elite cadre of instructors for the FEMA/Army Corps of Engineers Advanced Structures Specialist course for rescue engineers and teaching at the Department of Homeland Security's Incident Response to Terrorist Bombings course in New Mexico.

Building Stability Information Needs, Hazard Assessment, Mitigation, and Monitoring in Near-Collapse Buildings: Current Approach from the US&R Engineer's Perspective

At a collapsed building incident, emergency personnel conducting search and rescue at the site are focused on locating and extricating victims trapped in the building. The FEMA/USACE Urban Search and Rescue program utilizes rescue trained engineers (Structures Specialists) to work within the emergency command structure to minimize risk to the rescue personnel during these rescue operations. The Structures Specialist has the training and background to assess the damage and identify hazards to the rescuers. Evaluating the risk (and considering the reward), the engineer develops a mitigation plan to reduce risk to acceptable levels. This is accomplished with a toolbox of practical mitigation methods that have been standardized and proven through past experience and incidents. These mitigation methods, and the mitigation plan, vary in effort and levels of reduced risk. This presentation presents an overview of the current state of practice for hazard identification, assessment, mitigation, and monitoring in near-collapse buildings.

Presentation Slides

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Building Stability Information Needs, Hazard Assessment, Mitigation, and Monitoring in Near Collapse Buildings: Current Approach from the US&R Engineer's Perspective

Presentation:
Hollice F. Stone, PE, Stone Security Engineering, USACE StS, formerly CA-TF1

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- It is 2 am and the Fire Department has just responded to reports of a building collapse
- You are called in as a Structures Specialist to assist them in a safe and efficientt response
- You arrive on-scene and the chief asks "What do you think?"

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Audiences
- First Responders
- Emergency Managers
- Recovery Efforts

Timing
- Immediate
- Short Term
- Long Term

March 2010 Kabul Bombing

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Area Global Stability

Figure 1.33 Damaged buildings in vicinity of explosion.

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Building Global Stability

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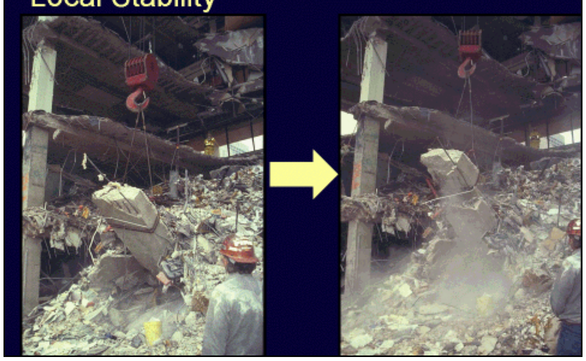
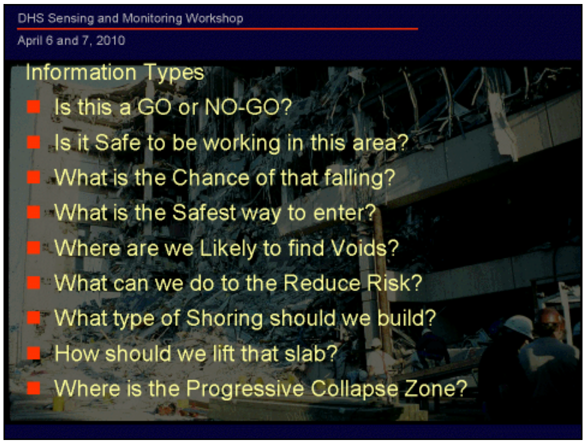
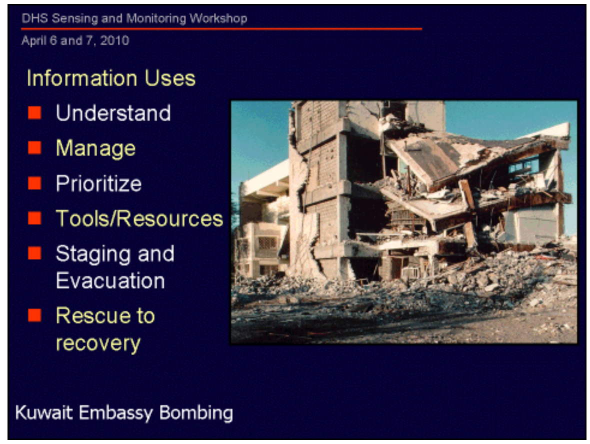
Local Stability

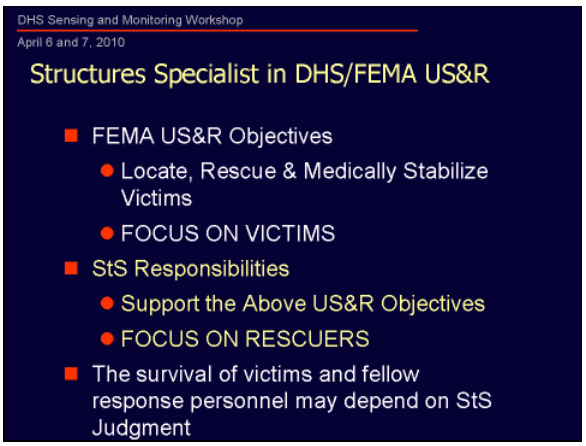


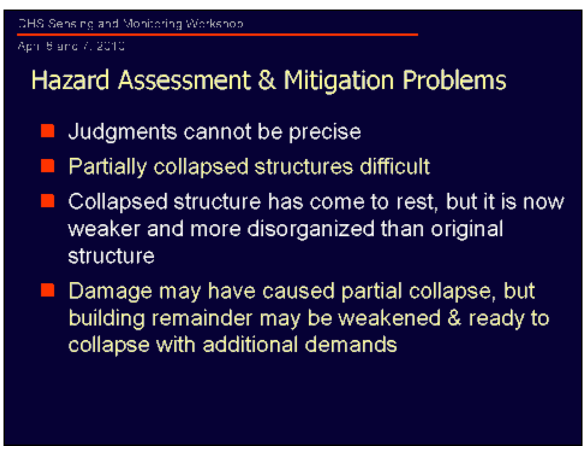
SESSION 2

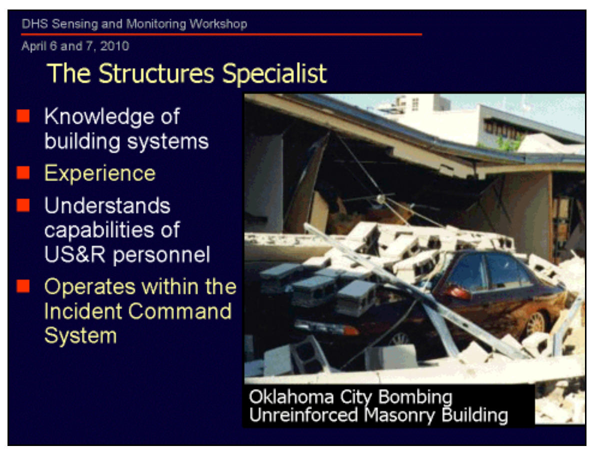
OVERVIEW OF INFORMATION NEEDS

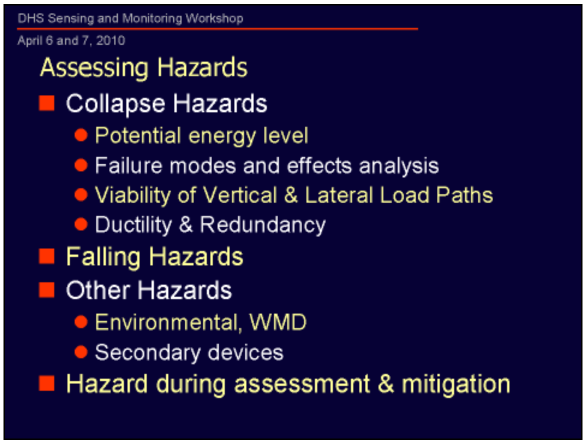








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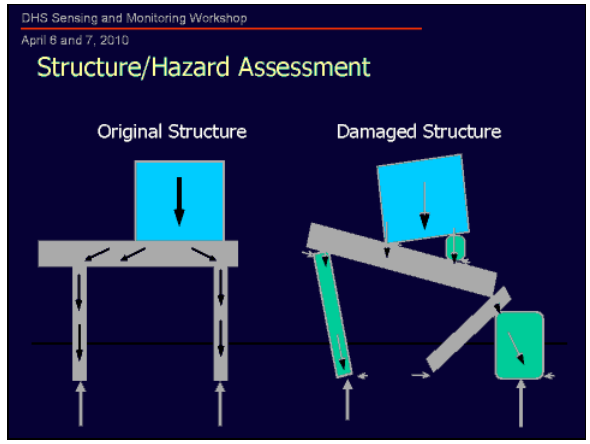
Assessing Hazards
Collapse Hazards
Potential energy level
Failure modes and effects analysis
Viability of Vertical & Lateral Load Paths
Ductility & Redundancy
Falling Hazards
Other Hazards
Environmental, WMD
Secondary devices
Hazard during assessment & mitigation


DHS Sensing and Monitoring Workshop
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Structure/Hazard Assessment
Original Structure
Damaged Structure


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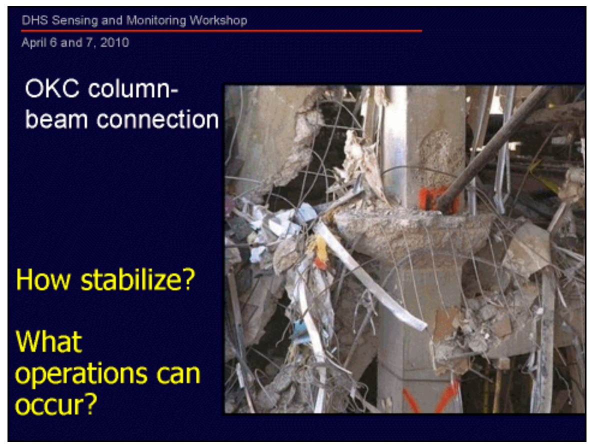
1998 Embassy Bombing
Ufundi House (non-target)
Where are Victims?
What are Hazards?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OKC column-beam connection
How stabilize?
What operations can occur?


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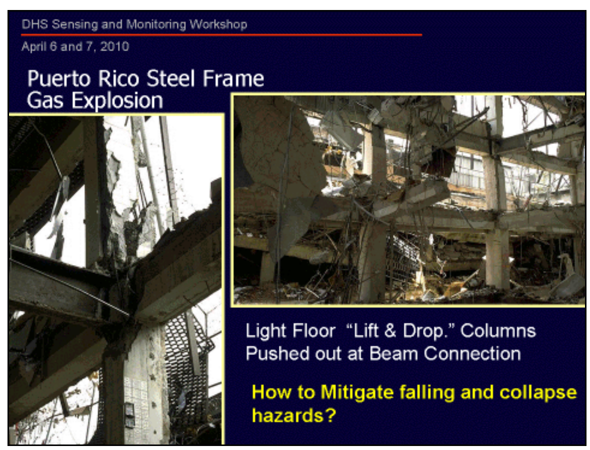
Mexico City Earthquake
10 story Type C1 Concrete
Outer bay floors collapsed
How to reduce risk for Searching Building?
Point of entry & safe havens?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Puerto Rico Steel Frame
Gas Explosion
Light Floor "Lift & Drop." Columns
Pushed out at Beam Connection
How to Mitigate falling and collapse hazards?

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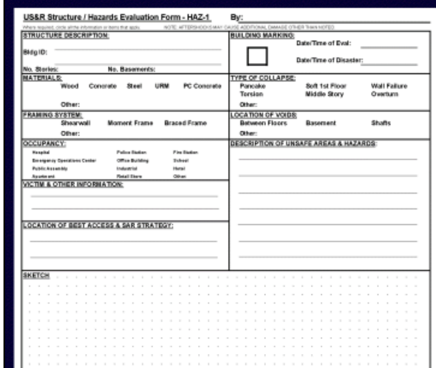

US&R Forms:

HAZ-1

HAZ-2 is large sketch area

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Structure/Hazard Assessment

- What caused the collapse?
- Has structure collapsed to a stable condition?
- Identify vertical & lateral systems
- Brittle or ductile behavior
- Check for redundancy
- Check for potential instabilities
  - Building stability
  - Rubble stability

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Structure/Hazard Assessment

- Visualize what could happen during additional demands
- What if there are additional demands - what is the plan? (safe haven areas / escape routes)
- Before changing the existing configuration (mitigation/rubble removal), evaluate the effect on the Load Path
- Can the hazards be mitigated to an acceptable level? What is risk during mitigation?

Hazard Mitigation

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Hazard Mitigation

- Following assessment, the StS considers alternatives that will reduce risk for US&R Ops
- Mitigation Plan is essential component of risk vs reward analysis
  - Mitigation will normally be done in a series of steps
  - As Reward of finding live victims decreases, additional mitigation should be planned and implemented to further decrease the risk to rescuers
  - Mitigation may be planned as a continuum that reduces risk, step by step
  - Hazards of implementing mitigation needs to be considered

---

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Hazard Mitigation Techniques

- Short-Term, Quick Mitigation
  - Avoid & Barricade
  - Remove (if easy)
  - Minimize Exposure
  - Spot Shoring
  - Monitoring (for immediate needs)
- Longer-Term, Resource Intensive Mitigation
  - Developed Shoring Systems
  - Remove (if difficult)
  - Monitoring (for long-term needs)
- US&R Forms: MIT 1

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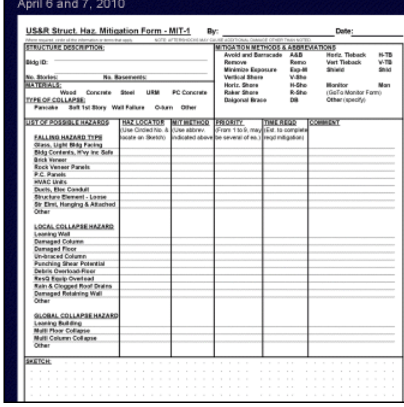

US&R Form MIT-1

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Simple Hazard Mitigation

- Avoid
  - Need effective barrier system
  - May be lowest risk option
- Removal
  - Lift off, push over, pull down
  - Operation may require Site Evacuation
  - May pose some risk to hidden victims

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Simple Hazard Mitigation

- Exposure reduction
  - Risk is a function of severity and exposure
  - How long do personnel need to be in the area?
  - Limit time exposed to hazard
  - Limit number of personnel exposed
  - Can be a short term, high risk option

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Hazard Mitigation

- Immediate need, short-term or longer-term Monitoring
  - Plumb Bob
  - Crack Gage
  - Smart Level
  - Laser Level
  - Total Station
  - Wireless Building Monitoring System

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Hazard Mitigation

- Short-term or longer-term Shoring
- Vertical & Lateral Shoring
  - Place Shoring and progressively upgrade shoring capacity and stability as operations continue
    - Class 1, Spot Shores
    - Class 2, Two-dimensional Shores
    - Class 3, Interconnect pairs of Class 2 to form three dimensional Shores

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Class 1 – Class 2 – Class 3



T Shore – 2 Post Vertical – Laced Post

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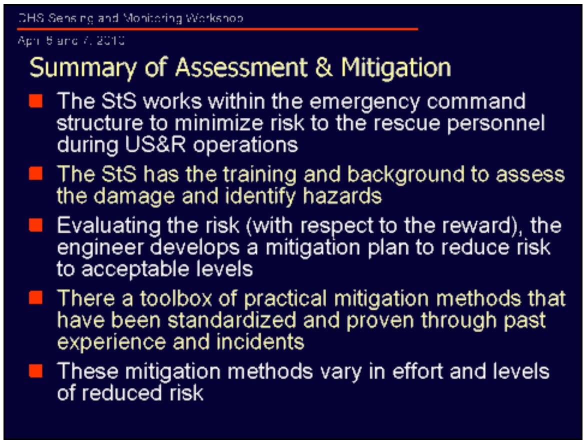
Lateral Bracing & Shores

Column Bracing **Building Bracing**



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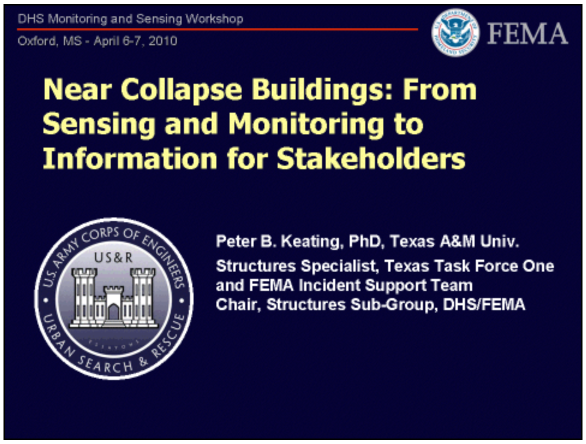
Peter Keating

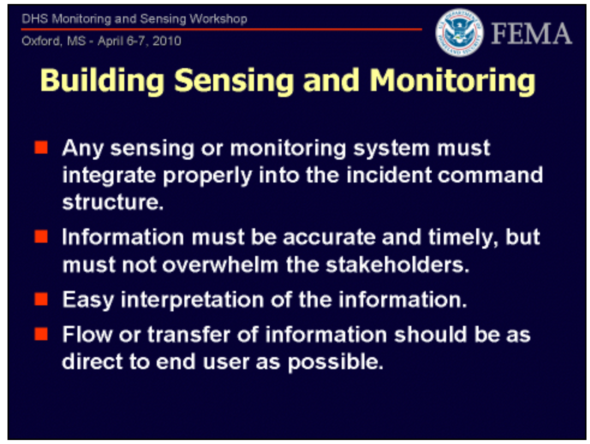
Dr. Peter Keating is an Associate Professor in the Civil Engineering Department and an Associate Research Engineer with the Texas Transportation Institute, both at Texas A&M University, College Station, Texas. He is also Director of the Structural and Materials Testing Laboratory. He received B.S., B.A. (architecture), M.S., and Ph.D. degrees from Lehigh University in Bethlehem, Pennsylvania. He teaches both graduate and undergraduate courses in structural engineering and performs research primarily in the area of structural fatigue. Other research has involved the development of fatigue repair procedures for steel highway bridges, the study of diaphragm cross frame influence on the fatigue and load distribution behavior of highway bridges, and the fatigue behavior of damaged and dented petroleum pipelines (for the Office of Pipeline Safety, U.S. DOT). He has also been a Structures Specialist with Texas Task Force One since 2000. He is the chairperson of FEMA's US&R Structures Subcommittee as well as a member on FEMA's Incident Support Team (Red). He is a registered Professional Engineer in the State of Texas.

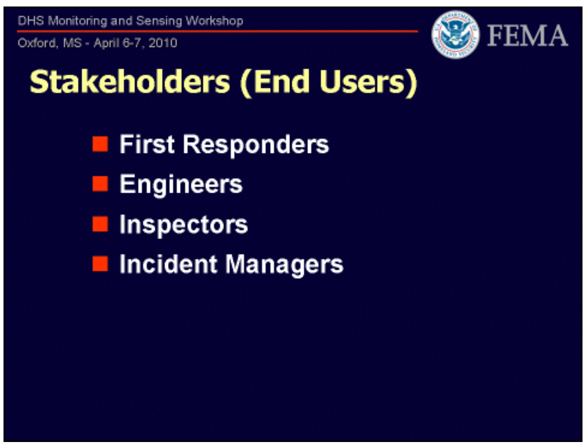
Near-Collapse Buildings: From Sensing and Monitoring to Information for Stakeholders

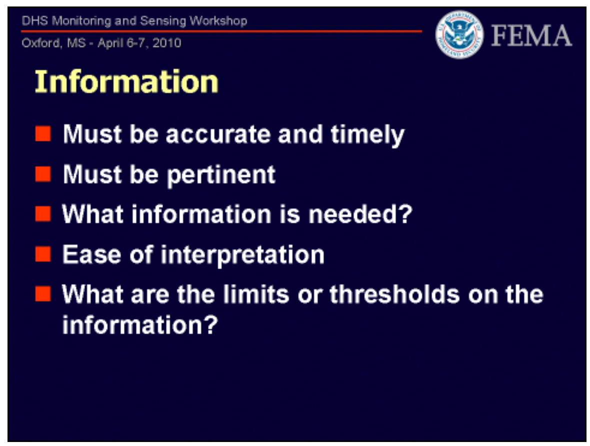
The objective of the DHS/FEMA Urban Search and Rescue program, which is outlined in the presentation, is to locate and rescue victims either trapped in void spaces or entombed. First responders need simple, real-time information on building stability in order to make decisions regarding rescue operations. This presentation explains the information and technology needs of first responder stakeholders when responding to a near-collapse building situation.

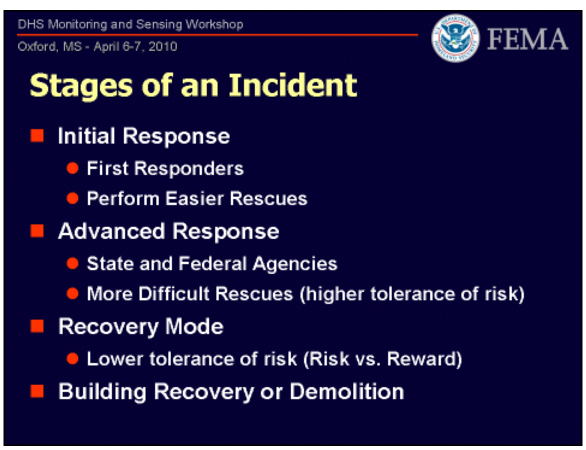
Presentation Slides

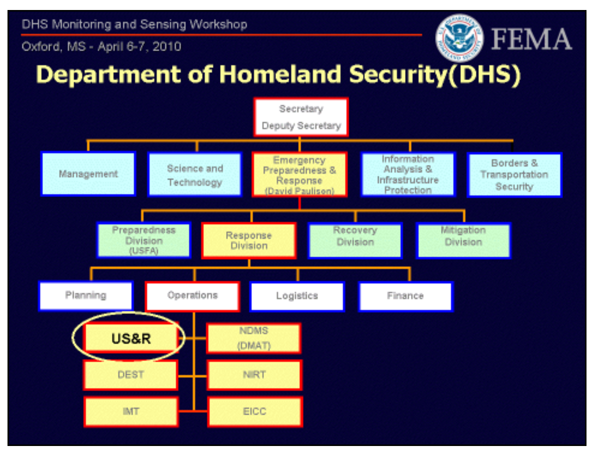






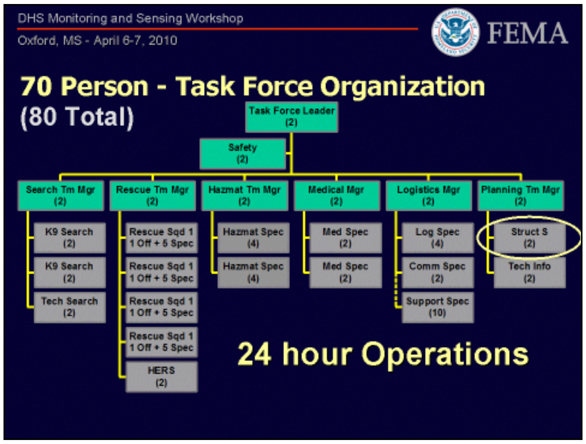


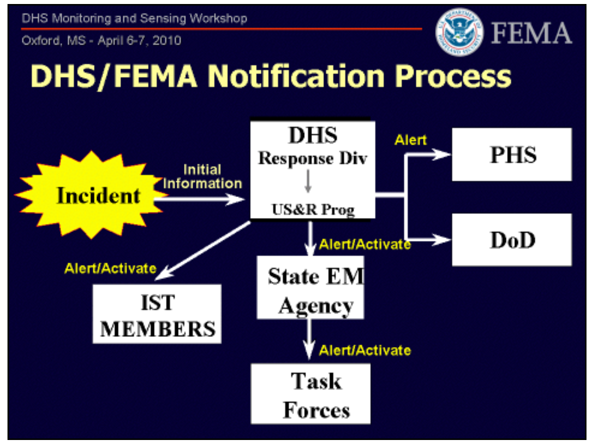


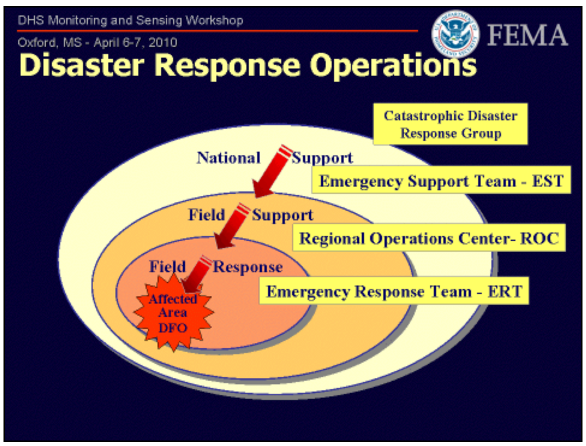


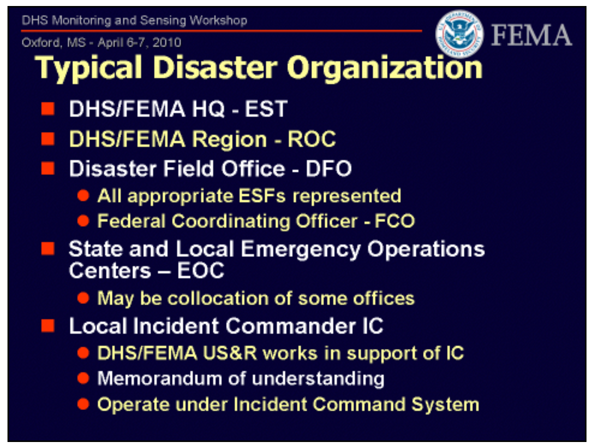
SESSION 2

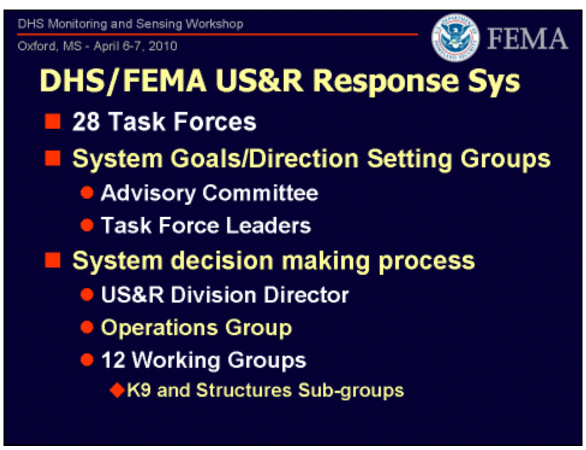
OVERVIEW OF INFORMATION NEEDS

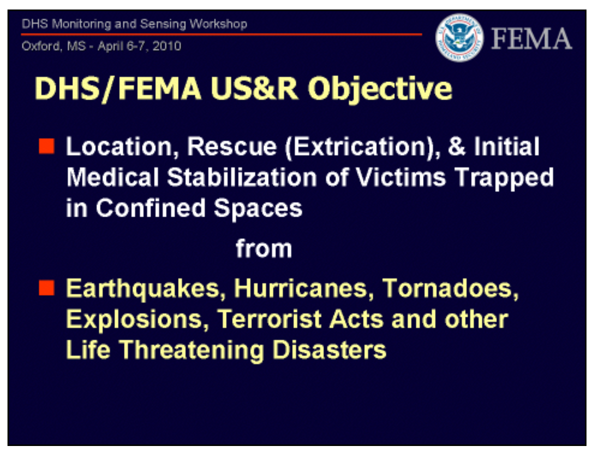


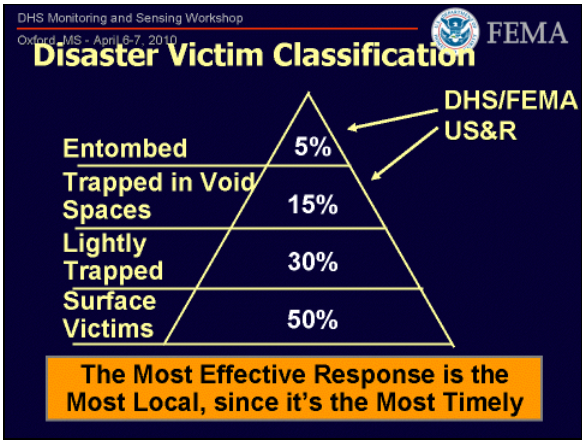








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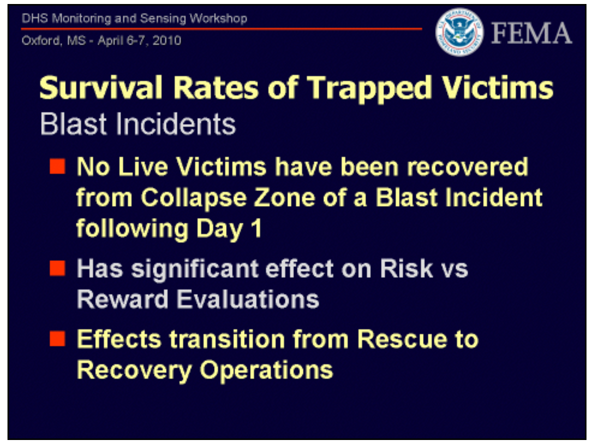
FEMA
Disaster Victim Classification
DHS/FEMA US&R
Entombed
5%
Trapped in Void Spaces
15%
Lightly Trapped
30%
Surface Victims
50%
The Most Effective Response is the Most Local, since it's the Most Timely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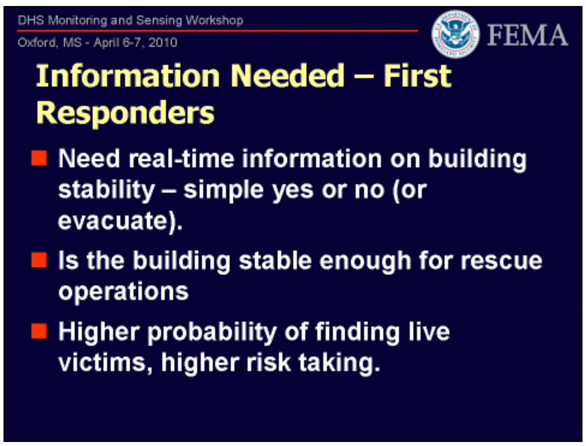
FEMA
Survival Rates of Trapped Victims
Blast Incidents
No Live Victims have been recovered from Collapse Zone of a Blast Incident following Day 1
Has significant effect on Risk vs Reward Evaluations
Effects transition from Rescue to Recovery Operations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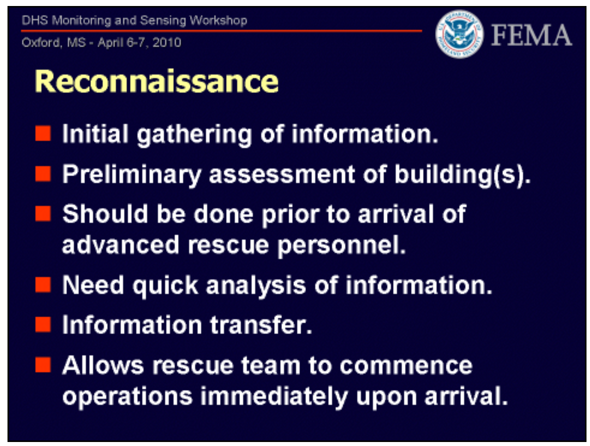
FEMA
Information Needed – First Responders
Need real-time information on building stability – simple yes or no (or evacuate).
Is the building stable enough for rescue operations
Higher probability of finding live victims, higher risk taking.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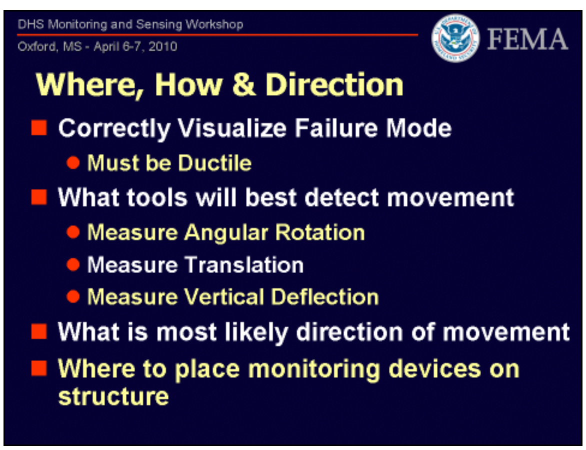
FEMA
Reconnaissance
Initial gathering of information.
Preliminary assessment of building(s).
Should be done prior to arrival of advanced rescue personnel.
Need quick analysis of information.
Information transfer.
Allows rescue team to commence operations immediately upon arrival.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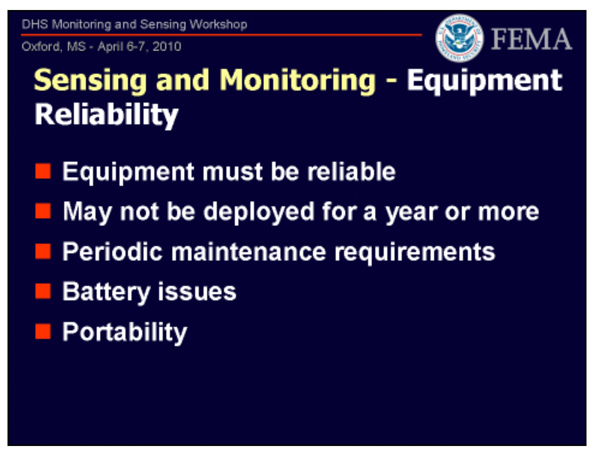
FEMA
Where, How & Direction
Correctly Visualize Failure Mode
Must be Ductile
What tools will best detect movement
Measure Angular Rotation
Measure Translation
Measure Vertical Deflection
What is most likely direction of movement
Where to place monitoring devices on structure


DHS Monitoring and Sensing Workshop
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FEMA
Sensing and Monitoring - Equipment Reliability
Equipment must be reliable
May not be deployed for a year or more
Periodic maintenance requirements
Battery issues
Portability

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Caution vs Alarm

- Need to know what is "Reasonable" or "Normal" Movement
  - Due to light winds
  - Due to change in Sun Angle
- Only valid is Failure Mode is Ductile
  - Otherwise, No Warning Time
- Levels may change
  - Based on incident's observation history
- Need Effective Warning System
  - See Emergency Comm Plan to follow

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Data Interpretation

- Most Challenging Aspect
  - No simple Rules
  - Consider overall context of Bldg & Incident
- Key Factors to Consider
  - Initial Conditions
  - Movement Magnitude & Rate
  - Movement Trend –Cyclic, Monotonic, Step
  - External Influences
- Must be timely and accurate

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Communication Protocols

- Need to strike a balance between Rapid Notification and Avoidance of False Alarms
  - Alert Threshold must be greater than "Normal", but less than Impending Collapse
- Must be able to Effectively Communicate any Alarm to Leadership
- A pre-determined "Alarm Level" need to be discussed & established with Leaders, so Rapid Response is Facilitated

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Hazard Mitigation

- Monitoring should include other hazards, such as falling debris, in addition to collapse

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Remote Engineering

- May not have engineering expertise on site
- Provide flow of pertinent information off site
- August 19, 2009 Bagdad bombing
  - Ministry of Finance
  - Ministry of Foreign Affairs

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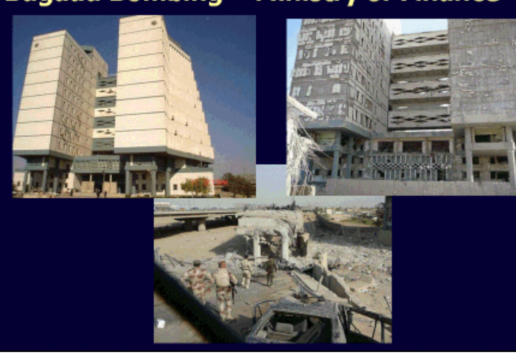
Bagdad Bombing – Ministry of Finance

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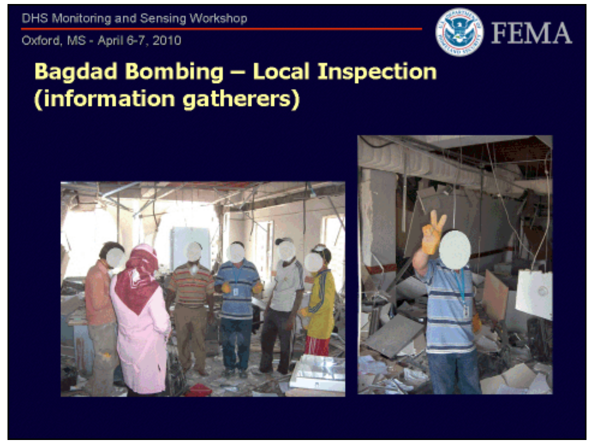
Bagdad Bombing – Ministry of Foreign Affairs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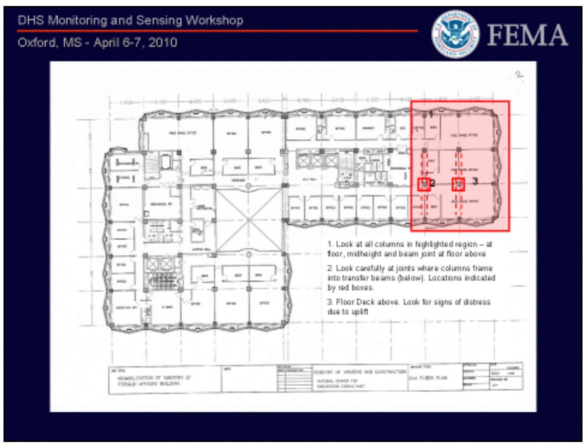
Bagdad Bombing – Local Inspection (information gatherers)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1. Look at all columns in highlighted region – at floor, midheight and beam joint at floor above
2. Look carefully at joints where columns frame into transfer beams (below). Locations indicated by red boxes.
3. Floor Deck above. Look for signs of distress due to uplift


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Current Demand on the Building

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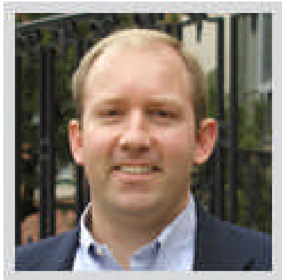
Richard Christenson

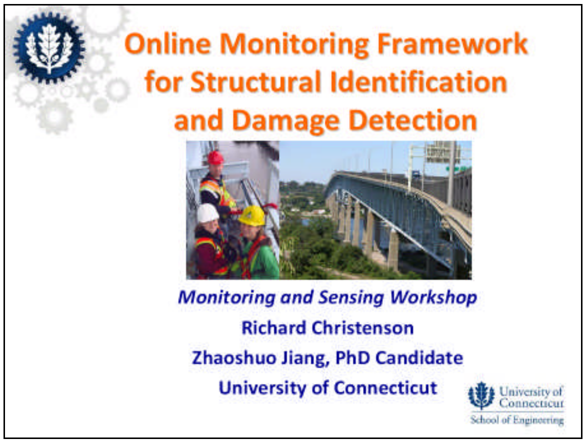


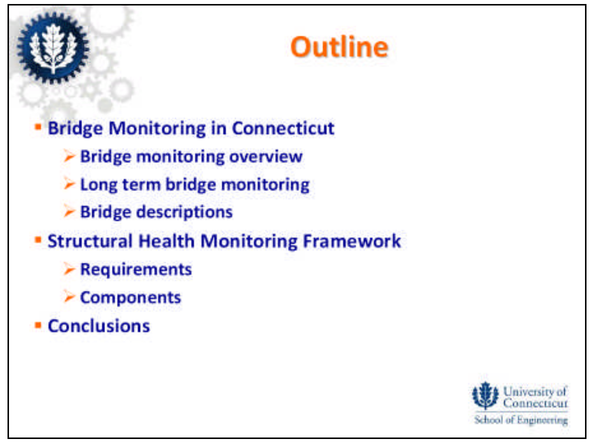
Dr. Richard Christenson is an Assistant Professor in the Department of Civil and Environmental Engineering (CEE) at the University of Connecticut. He is the United Technologies Corporation Professor in Engineering Innovation within the CEE Department. Prior to starting at UConn in January 2006, he was an Assistant Professor of Civil Engineering at the Colorado School of Mines for four years. Dr. Christenson received his Ph.D. from the University of Notre Dame in 2002. His research and teaching interests are in structural engineering, particularly in the areas of structural dynamics and experimental research. Dr. Christenson's current research is in the areas of bridge monitoring, smart damping technologies for buildings and bridges, and real-time hybrid testing methodologies and encompasses analytical studies, small, medium, and large-scale laboratory experiments, and full-scale field testing.

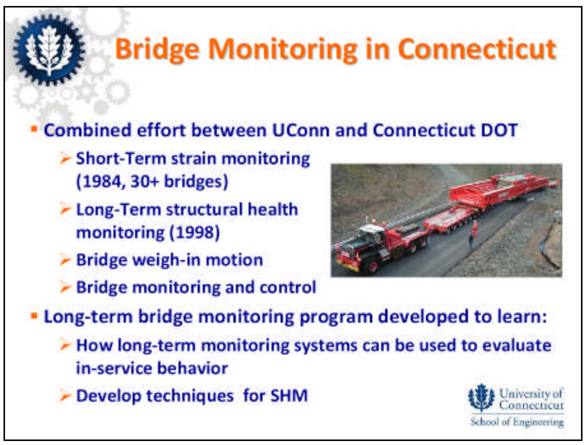
Online Monitoring Framework for Structural Identification and Damage Detection

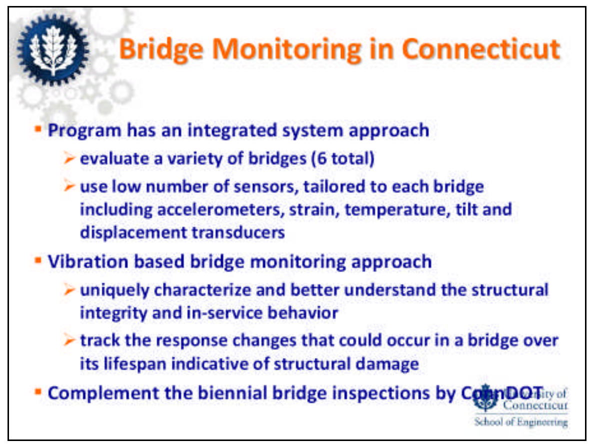
Structural health monitoring (SHM) technologies can be applied to civil infrastructure such as buildings and bridges for automated structural identification and monitor damage detection. To provide necessary information to the appropriate personnel in a timely manner, the SHM system requires an automated data acquisition and analysis framework and a user interface that is flexible and can communicate information in real time. For highway bridges the inventory is geographically distributed and SHM information needs to be accessible remotely. Bridge structural systems vary widely in design and use and the resulting SHM systems themselves are very different. A vibration-based bridge monitoring approach is employed where accelerometers and strain, temperature, tilt and displacement transducers along with modular data acquisition hardware are used to uniquely characterize and better understand the structural integrity and in-service behavior of six permanently monitored highway bridges located in Connecticut. The monitoring systems are intended to complement the biennial bridge inspections by the Connecticut Department of Transportation (ConnDOT) and are used to track the response changes that could occur in a bridge over its lifespan indicative of structural damage. Real-time information is provided to ConnDOT personnel through an online open-source real-time data acquisition, analysis, and dissemination framework. An internet-based java tool is employed to provide remote access to the distributed bridge monitoring data. The online bridge monitoring framework is shown to be practical and useful in providing timely structural identification and damage detection of highway bridges in Connecticut. The lessons learned from long-term vibration-based bridge monitoring and the general framework developed for this purpose can be extended to the monitoring and sensing of near-collapse buildings.

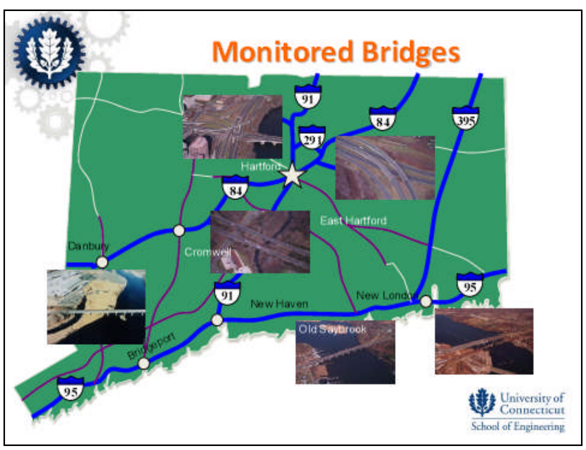
Presentation Slides











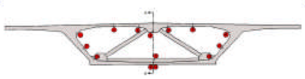
Post-Tensioned Box Girder Bridge

- 3 span, 5 cell, curved cast in place concrete box girder bridge with two, single integral columns
- Cracking in pier caps, columns and deck
- Monitoring began in 1999
- Sensors: 12 Temp., 6 Tiltmeters, 16 Accelerometers


Multi-span Segmental Post-Tensioned Bridge

Multi-span Segmental Post-Tensioned Bridge

- Nine continuous spans
- Single cell in each direction
- Cracking noted in inspections
- Temperature monitoring recommended by designers, able to show:
- Temperature variations greater than AASHTO design specs
- Strains/stre not a problem

Steel Box Girder Bridge

Steel Box Girder Bridge

- Dual steel tub-girder with composite concrete deck
- Varying radii and elevations complicate analysis
- Three sets of three continuous spans, each simply supported
- Cracking observed in tall, slender columns during biennial inspection
- Monitoring began in 2001
- Sensors: 8 Temperature, 6 Tilt, 8 Accelerometers

Steel Multi-Girder Bridge

Steel Multi-Girder Bridge

- Three simply-supported spans with 3 lanes in Interstate
- Typical slab-on-girder bridge with composite action
- 20 strain sensors located on first two spans
- Monitoring began in 2004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Steel Truss Bridge

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Steel Truss Bridge

- Wireless monitoring system used to evaluate hangers for central hung span


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Steel Truss Bridge

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Multi-Span Steel Girder Bridge

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Multi-Span Steel Girder Bridge

- New bridge
- Limited truck traffic
- Monitoring system:
- 4 transducers
- 6 tiltmeters
- 16 strain gages
- 22 accelerometers
- Monitoring began in 2007
- Collecting data for automobiles
- Need modifications for better clarity

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Requirements of SHM Framework

- Bridge inventory is geographically distributed and SHM information needs to be accessible remotely
- Bridge structural systems vary widely in design and use and the resulting SHM systems themselves are very different
- Resources are limited – automated assessment of the structure in a timely and efficient manner

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SHM Framework for Bridge Monitoring in Connecticut

- Leverage advances in internet, computer technologies and software development
- Modular data acquisition hardware to accommodate variety of different sensors
- Real-time information provided to ConnDOT personnel through an online user driven java tool
- User interface is flexible and can communicate information and facilitate assessment by inspectors/engineers

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SHM Framework for Bridge Monitoring in Connecticut

- Three components of the SHM framework
  - Data Acquisition
  - Data Processing, Archiving and Alerting
  - Real-time Data Viewer

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SHM Framework for Bridge Monitoring in Connecticut

- Three components of the SHM framework
  - **Data Acquisition**
  - Data Processing, Archiving and Alerting
  - Real-time Data Viewer

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Data Acquisition

- Utilizing National Instruments Data Acquisition Hardware
  - Powerful, modular and flexible
  - 60+ modules to connect to a variety of different sensors
  - Compact system

- Collected on-site with PC
  - Remote access with DSL or 3G wireless

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SHM Framework for Bridge Monitoring in Connecticut

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  - **Data Acquisition**
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Data Processing, Archiving and Alerting

- Data Processing
  - Process the data locally in the field on DAQ PC
  - Labview software provides graphical programming in a powerful environment
  - Passive monitoring approach in Connecticut (unknown excitation force) coupled with limited numbers of sensors allow for global damage detection
  - Multiple analysis tools and methods are implemented to avoid false positives (e.g. modal analysis, peak responses, response distributions, …)

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Data Processing, Archiving and Alerting

- Data Processing

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Data Processing, Archiving and Alerting

- Data Processing
- Data Archiving
  - Triggered and scheduled events are saved on the local PC temporarily
  - Nightly the data is saved to a ConnDOT FTP server – automated process

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Data Processing, Archiving and Alerting

- Data Processing
- Data Archiving

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Data Processing, Archiving and Alerting

- Data Processing
- Data Archiving
- Alerting
  - Automated email alerts can be generated when set thresholds are exceeded

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SHM Framework for Bridge Monitoring in Connecticut

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SHM Framework for Bridge Monitoring in Connecticut

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Real-Time Data Viewer

- Enhanced/expanded version of NSF-sponsored Network for Earthquake Engineering Simulation (NEES) Real-time Data Viewer (RDV)
- Data and video are synchronized using Data Turbine
- Provides internet-based interface for viewing raw and/or processed data in real-time
- Provides playback function (DVR functionality)
- Open source, Java based
  - Requires no software (aside from java)
  - Can be modified to meet specific needs

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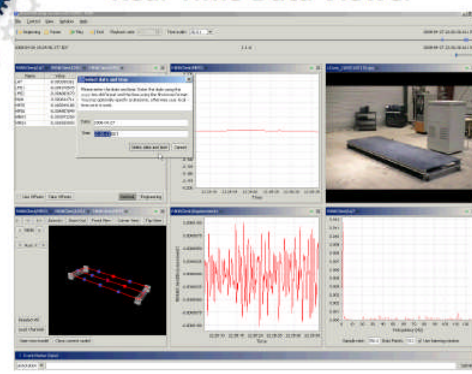
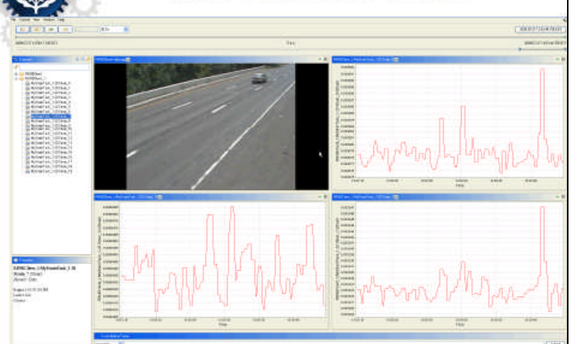
Real-Time Data Viewer



Real-Time Data Viewer



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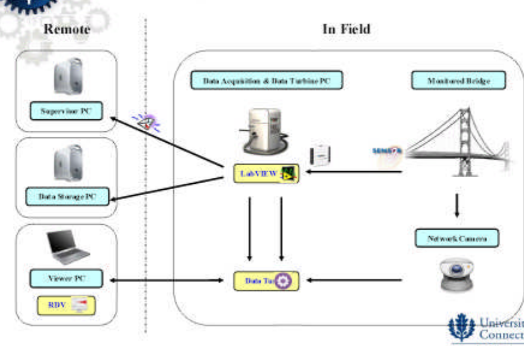
System Architecture



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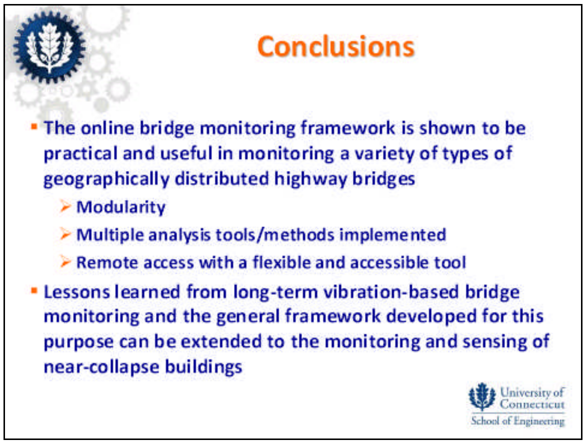

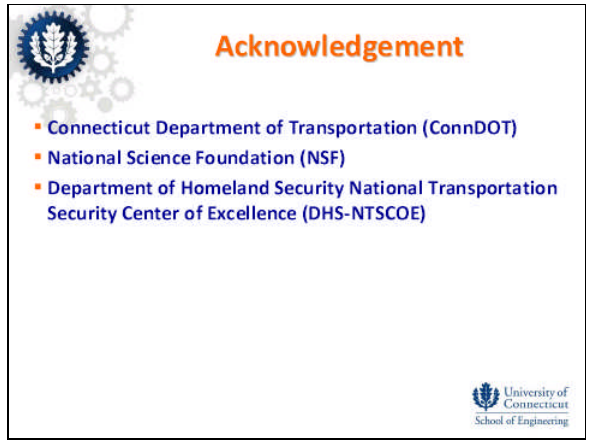

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Michael Barker

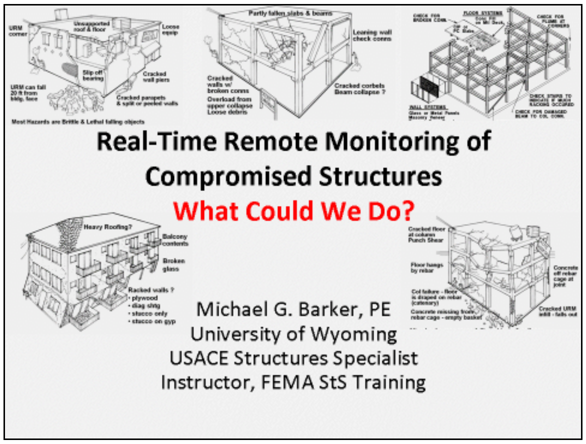
Michael G. Barker, Ph.D., PE is a Professor at the University of Wyoming after being at the University of Missouri-Columbia for 13 years. He teaches courses in Statics & Elementary Strength of Materials, Dynamics, Structural Dynamics, Design Philosophy, Building Systems, and Steel Design. He has conducted experimental and analytical research in the elastic and inelastic behavior of structural systems and has consultant experience in forensic engineering.

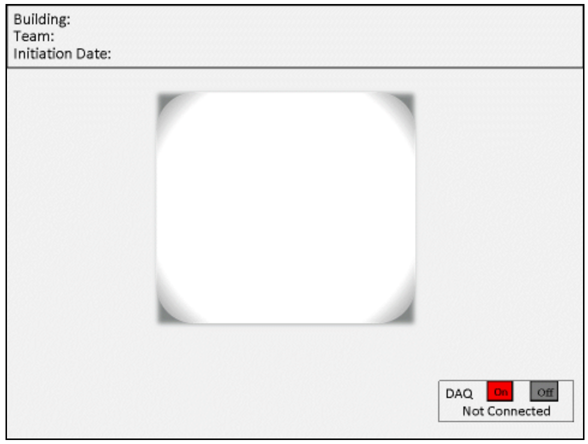
Michael was a Structures Specialist for DHS/FEMA’s US&R Missouri Task Force 1 before moving to Wyoming. He was also an original member to the FEMA Technical Working Group (now the Structures Sub Group). Michael was deployed to the World Trade Center Response with the Missouri Task Force. He is currently working with the U.S. Army Corps of Engineers (USACE) US&R Structures Specialist training program as a lead instructor. He also is an advisor to the Corps’ US&R Program in such areas as general program operations, extreme cold weather deployability, and technical rescue training for the military..

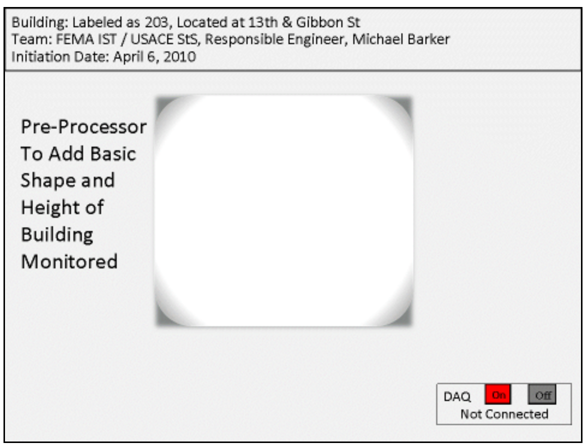
Real-Time Remote Monitoring of Compromised Structures during Catastrophic Events

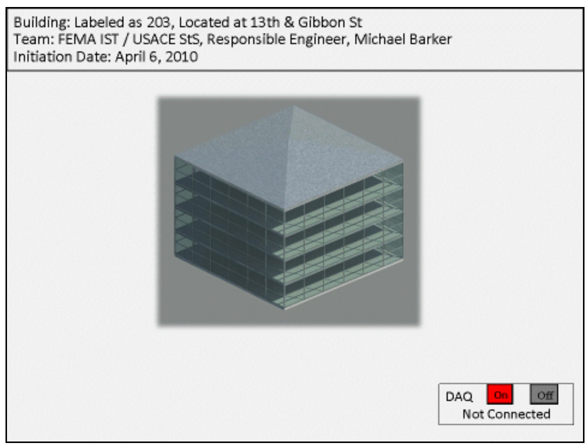
The United States has been preparing to respond to building damage or collapse events for well over a decade. The main catastrophic events of concern are natural disasters such as earthquakes or industrial accidents such as explosions and terrorism events. A partially collapsed or otherwise compromised structure with a potential for further collapse endangers rescue personnel while rescue operations are in progress. Current building safety monitoring techniques include attaching digital levels, visual crack width indicators, and other manual sensors to critical components in the structure or set up surveying apparatus to sight on a target located on the building. The devices are periodically visited and recorded over time for comparison to ascertain structural movements and infer safety conditions. Significant problems with the current practice are that there is risk to the device inspectors at the data collection intervals, the devices will be located in the dangerous "hot" zones of the structure that should remain evacuated, critical information is collected only at the data collection intervals and any movement of the structure that may occur between the data collection intervals is not immediately detected, it is difficult to track structural response during the event with manual interval readings, and there is no real-time early warning system for rescue personnel with the spaced monitoring and comparison intervals. This presentation demonstrates a promising real-time building monitoring system for rescue operations that is expedient in setup, efficient and robust for monitoring, and will continuously monitor the damaged building for immediate safety warnings.

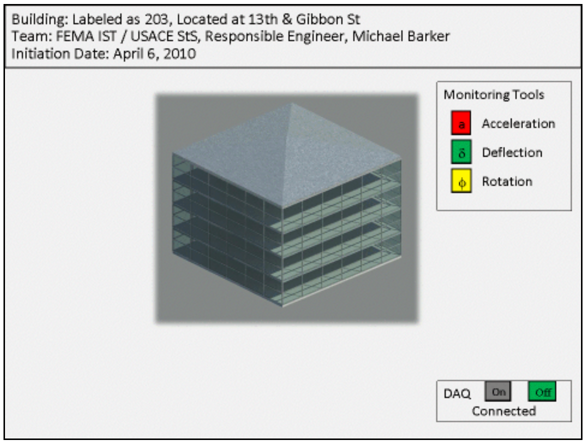
Presentation Slides



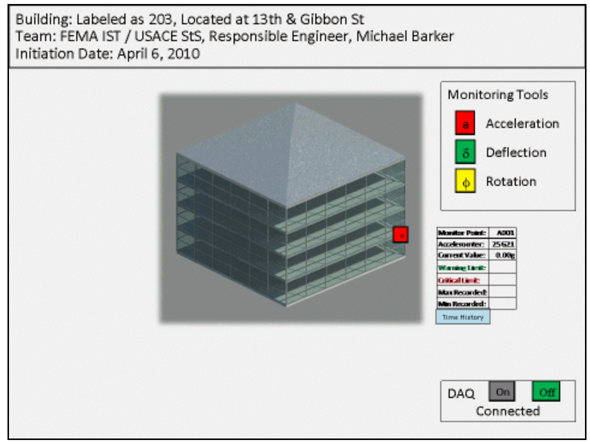








Building: Labeled as 203, Located at 13th & Gibbon St
Team: FEMA IST / USACE StS, Responsible Engineer, Michael Barker
Initiation Date: April 6, 2010
Monitoring Tools
Acceleration
Deflection
Rotation
DAQ
On
Off
Connected



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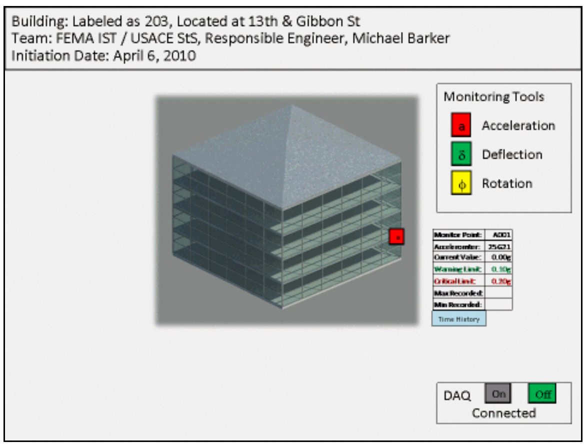

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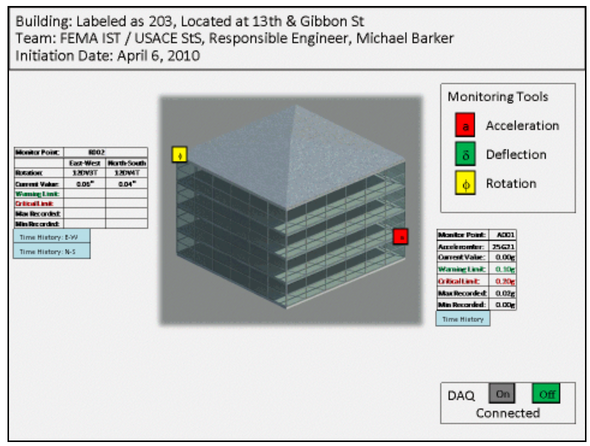

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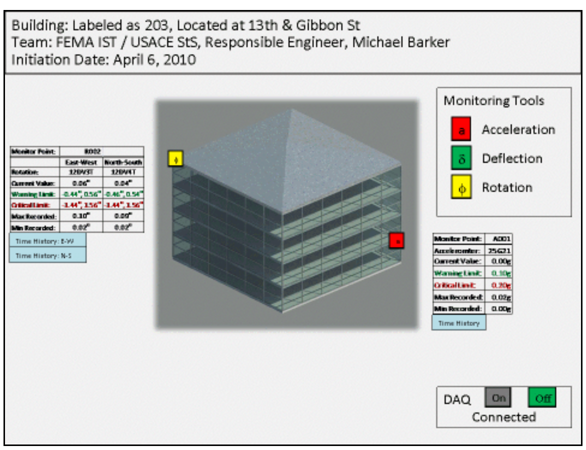

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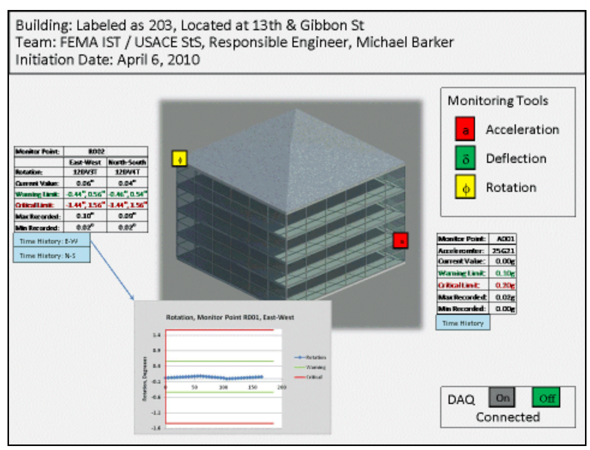

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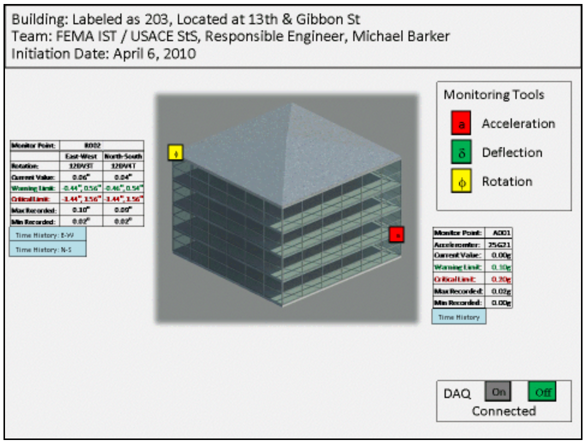

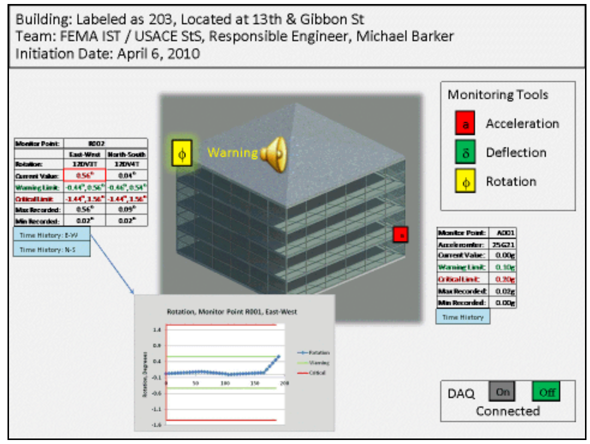

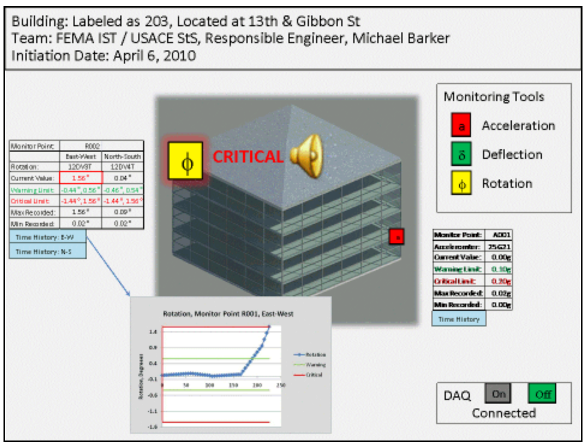

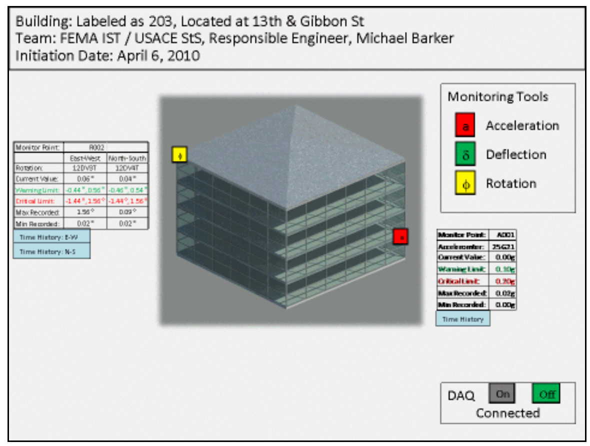

Benefits

Current Practice	Possible Practice
Attach manual devices, setup TS, WBMS*	Attach monitor devices
Periodically visit (in "hot" zone) and record	Continuous record (avoid "hot" zone)
Manually track structural response between interval readings	Automatically track structural response continuously
Infer safety conditions	Infer safety conditions
Delayed safety warning	Immediate safety warning

* The current WBMS is a wireless system, but limited in capability and very bulky

How to Get There

- Hardware Development
  - Application of current technology
- Software Interface Development
  - Pre-processors for site-specific building representation
  - GUI for input and output (devices, limits, warnings, tracking) and hardware integration
  - Documentable record of monitoring exercise
- Monitoring Protocols for structure types
  - Critical information to monitor
  - Defining limits for early warning system
- Integration & Formal Testing
  - FEMA/USACE Structural Specialist training courses
  - Implement system on mock event training
- Disaster Event Implementation

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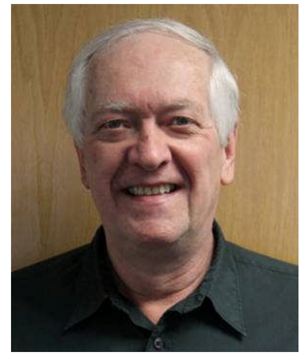
Wayne Haase



Wayne C. Haase is president of Summit Safety, Inc, of Devens, Massachusetts. Summit Safety was formed after the tragic warehouse fire in Worcester, Massachusetts, in 1999 in which six firefighters perished. Summit Safety has developed the Pathfinder System, which enables firefighters to quickly locate each other and exits under zero-visibility conditions. Dr. Haase received a BS, MS, and the Degree of Electrical Engineer from MIT and received a Ph.D. in Electrical Engineering from Stanford University. He has been a founder in several companies, and has been a consultant to approximately 100 companies in the fields of aerospace systems, biomedical systems, consumer/industrial electronics, and test & measurement systems. He has published approximately 50 technical papers and is a co-inventor on 19 U.S. Patents. Dr. Haase has been the Principal Investigator for 12 Small Business Innovation Research (SBIR) contracts. He is a member of the Electronic Safety Equipment Technical Committee of the National Fire Protection Association, which sets standards for all electronic systems for the fire service.

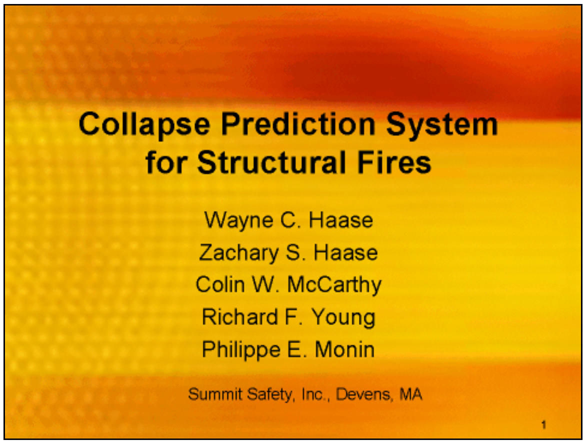
Collapse Prediction System for Structural Fires

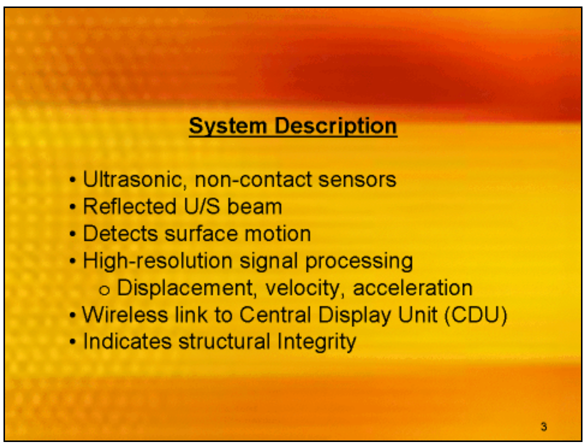
This presentation discusses the current stage of development of a monitoring system designed to provide advance warning of structural collapse for both new and existing buildings, particularly during structural fires. The system was developed under SBIR funding from National Institute of Standards and Technology (NIST) and DHS, and focuses on providing warning of impending roof and floor collapse in residential structures. The prototype system has been tested in live burns conducted at Underwriters Laboratories (UL) as well as four structural fires conducted by NIST.

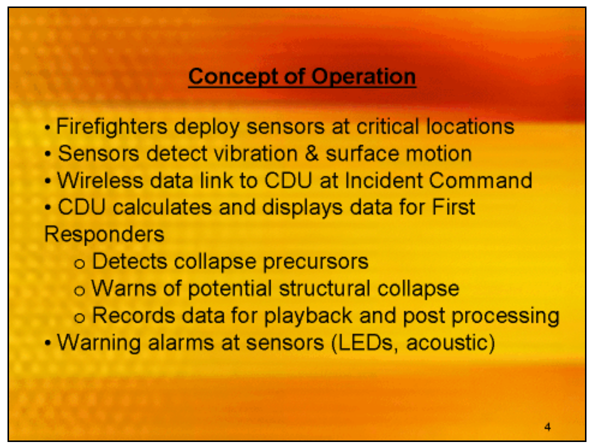
The prototype sensor utilizes a pair of ultrasonic transducers to detect small vibrations that are precursors of structural collapse. One transducer sends an ultrasonic beam toward the surface and the second transducer receives the reflected signal from the surface. Internal microprocessor-based electronics calculate surface displacement using an interferometric technique. The sensor detects changes in position, velocity, and acceleration from structural surfaces even in the presence of thick smoke, dust, or fog, which could render an optical or laser-based system unusable. The wireless prototype sensor can be deployed in a matter of seconds.

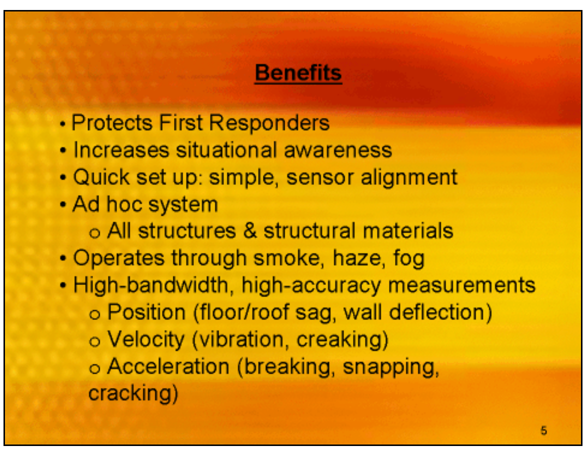
The system was tested in structural fires with both dimensional lumber as well as lightweight construction materials. The system was able to provide consistent warning times independent of the materials and techniques used in the construction of the test structures. In all of the tests, the system provided a minimum warning time of at least two minutes prior to collapse for all of the tests.

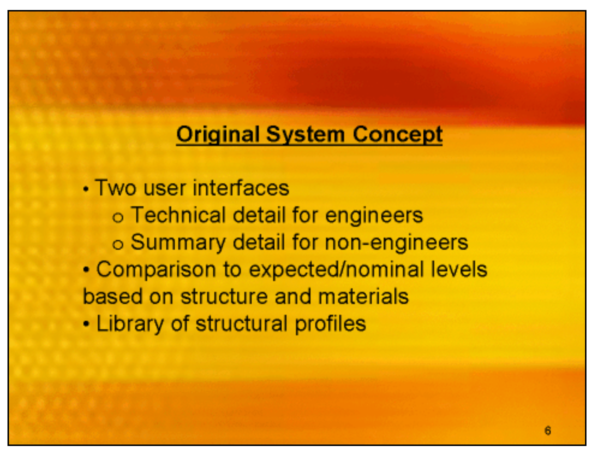
Presentation Slides









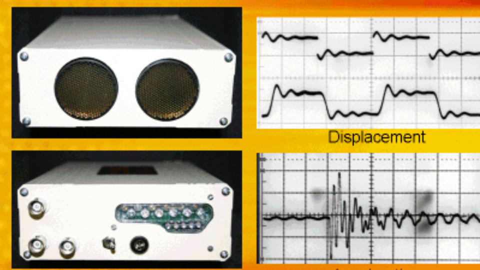


Original System Concept

- Two user interfaces
  - Technical detail for engineers
  - Summary detail for non-engineers
- ~~Comparison to expected/nominal levels based on structure and materials~~
- ~~Library of structural profiles~~

7

Generation-1 Prototype Sensor



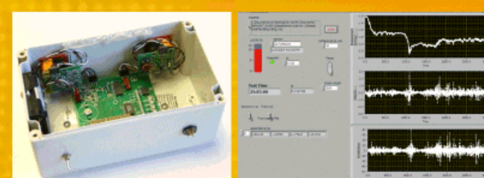
8

Generation-1 Prototype Sensor

Parameter	Value
Ultrasonic frequency	100 KHz
Standoff distance	4 meters (12 feet)
Bandwidth	100 Hz
Displacement RMS noise	15 μm (6 μ in)
Velocity RMS noise	2 μm/sec (92 μ in/sec)
Acceleration RMS noise	62 μ m/sec² (2.46 x 10⁻³ in/sec²) 6.4 μ g [ADXL327: 2200 μ g]

9

Generation-2 Prototype Sensor



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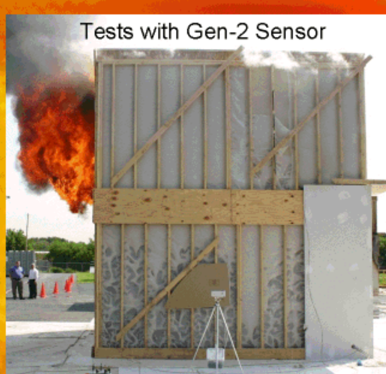

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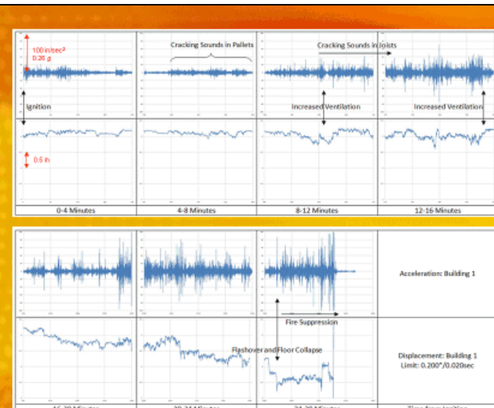
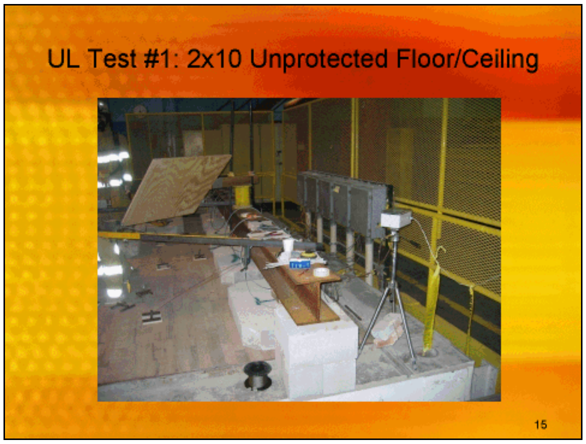
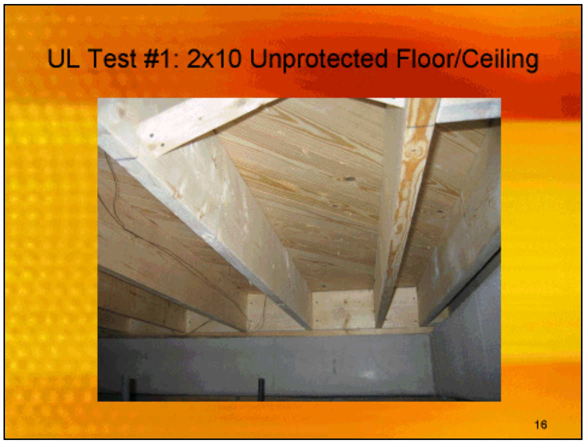


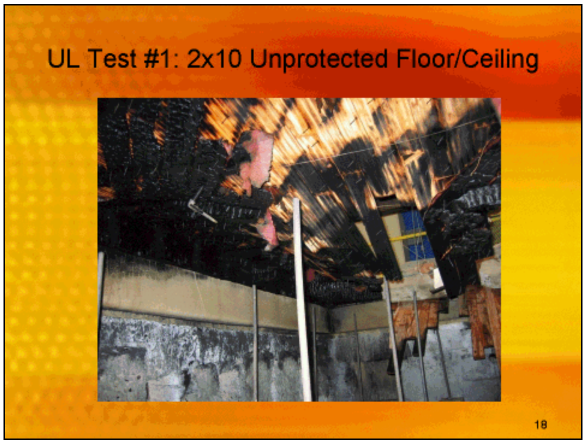

Generation-3 Wireless Sensor
13

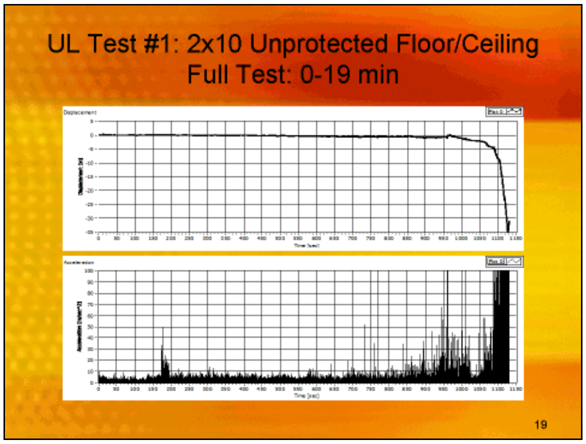

UL Test #1: 2x10 Unprotected Floor/Ceiling
14

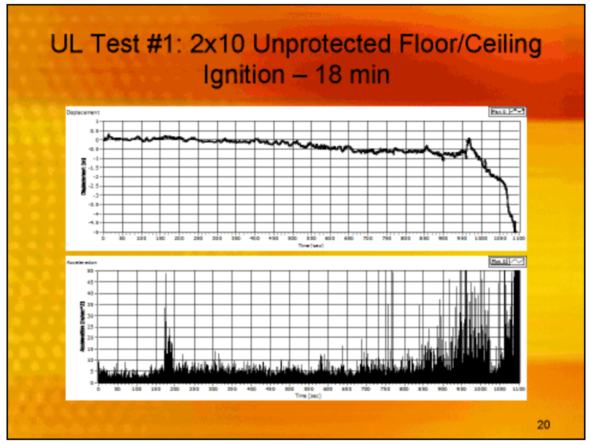

UL Test #1: 2x10 Unprotected Floor/Ceiling
15

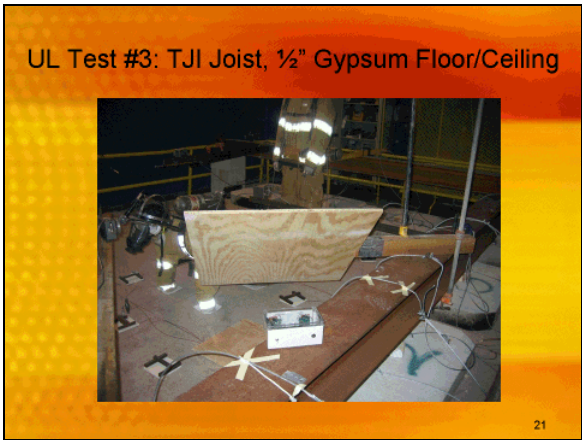

UL Test #1: 2x10 Unprotected Floor/Ceiling
16

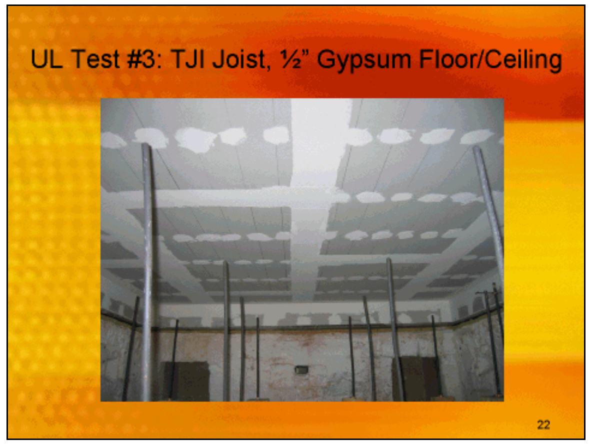

Test #1: 2x10 Unprotected Floor/Ceiling
17

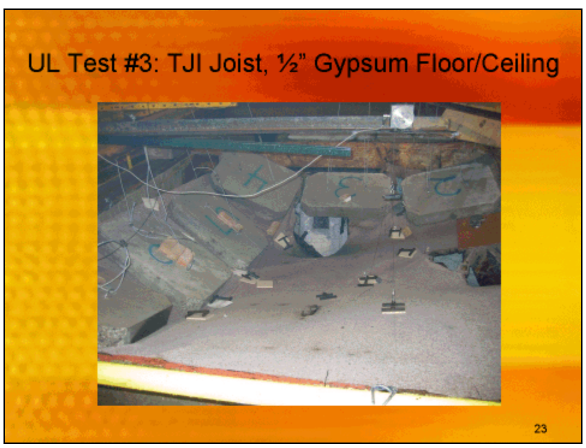

UL Test #1: 2x10 Unprotected Floor/Ceiling
18


UL Test #1: 2x10 Unprotected Floor/Ceiling
Full Test: 0-19 min
19


UL Test #1: 2x10 Unprotected Floor/Ceiling
Ignition – 18 min
20


UL Test #3: TJI Joist, ½" Gypsum Floor/Ceiling
21


UL Test #3: TJI Joist, ½" Gypsum Floor/Ceiling
22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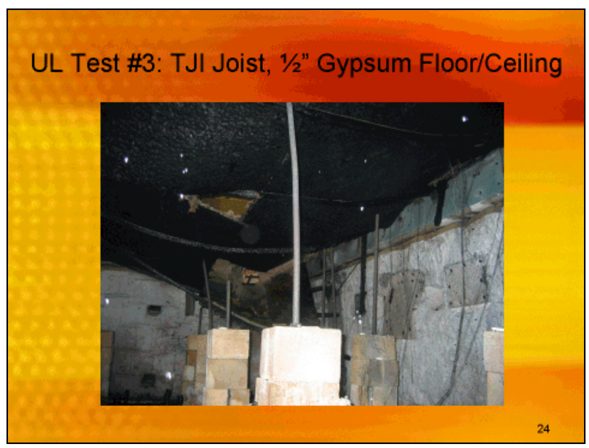
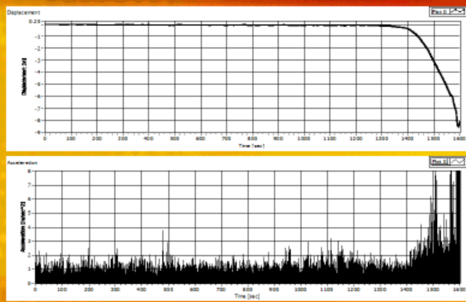
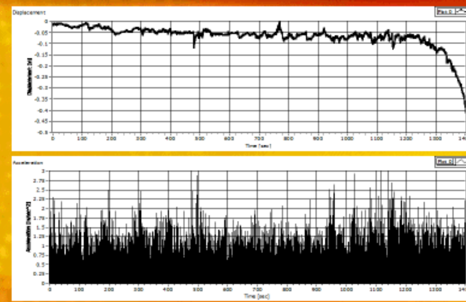

UL Test #3: TJI Joist, ½" Gypsum Floor/Ceiling
24

UL Test #3: TGI Joist, ½" Gypsum, Floor/Ceiling
Full Test: 0-27 min



25

UL Test #3: TGI Joist, ½" Gypsum, Floor/Ceiling
Ignition – 23 min

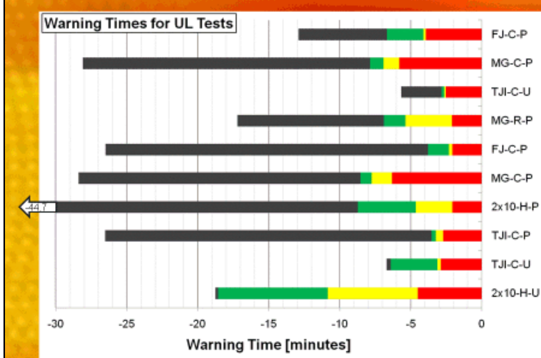


26

Warning Times for UL Tests

Test	Floor	Collapse (min)	Warning Time (minutes)		
1	2x10-H-U	18.8	18.6	10.9	4.5
2	TJI-C-U	6.7	6.4	3.1	2.9
3	TJI-C-P	26.5	3.6	3.2	2.7
4	2x10-H-P	44.7	8.7	4.7	2.1
5	MG-C-P	28.4	8.5	7.8	6.3
6	FJ-C-P	26.5	3.8	2.3	2.1
9	MG-R-P	17.2	6.9	5.4	2.1
10	TJI-C-U	5.7	2.8	2.6	2.6
12	MG-C-P	18.6	7.9	6.9	5.8
13	FJ-C-P	6.4	6.7	4.1	3.9
	Maximum:	44.7	18.6	10.9	6.3
	Average:	21.5	7.4	5.1	3.5
	Minimum:	5.7	2.8	2.3	2.1
	Standard Deviation:	11.8	4.4	2.7	1.6

27



28

Proposed Final Package

29

Every Tool
has its
Limitations

30


31

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SESSION 4
EQUIPMENT AND TECHNIQUES

Vincent Chiarito

Vince Chiarito is a research structural engineer in the Structural Engineering Branch, Geosciences and Structures Division, Geotechnical and Structures Laboratory at the Waterways Experiment Station of the U.S. Army Engineer Research and Development Center in Vicksburg, Mississippi.

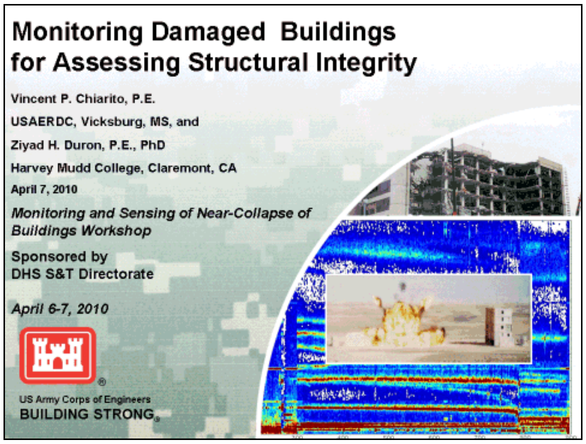
Mr. Chiarito began his employment at USAERDC (formerly WES) in November, 1980. Since, he has supported structural engineering research for civil and military projects. Project work has included prototype and model vibration studies of several different types of structures and systems and the seismic and blast response of these structures. He has authored or coauthored many technical reports and papers on the structural engineering research efforts and products of the Corps.

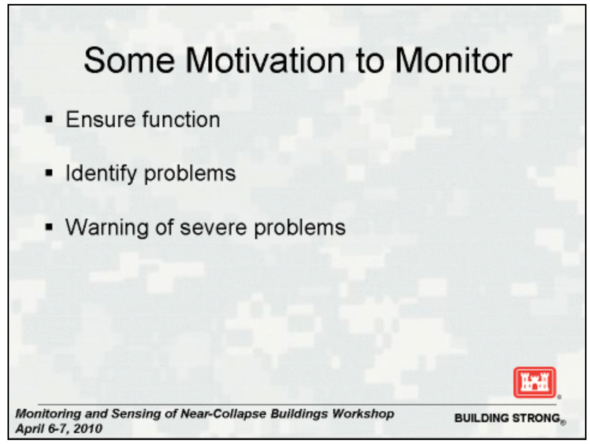
Mr. Chiarito received his B.C.E. and M.C.E. in Civil Engineering from the University of Delaware.

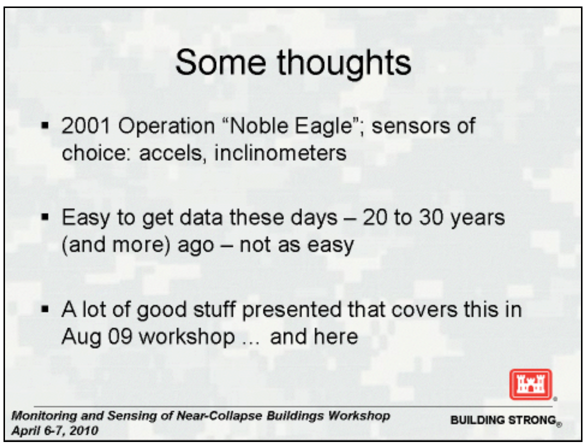
Monitoring Damaged Buildings for Assessing Structural Integrity

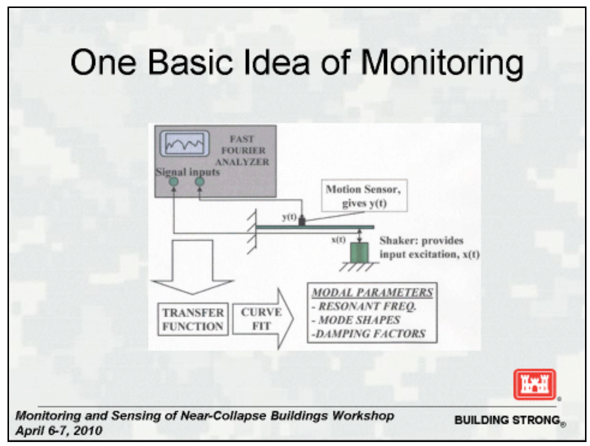
Monitoring damaged buildings for assessing existing integrity or predicting the onset of instability involves identifying basic dynamic properties. The damage to the buildings could result from a number of different stimuli, such as fire, earthquake, or blast effects. Baseline information of the initial as-built state is not always possible; hence it is important to understand how to compare results of monitoring damaged buildings in real time of relative states of performance or service. With steady and continual advances in sensor technology, data acquisition capabilities, and new signal and time domain processing algorithms acquiring the information in real time of a building's response is doable and making real time relative comparisons feasible. There are a number of parameters and changes in parameters to consider in assessing the integrity of a damaged building or system. Damage indicators do exist in the form of computing the changes in mode shapes and the flexibility coefficients, which are obtained experimentally or through physical monitoring. The use of fixed or hardwired systems and wireless systems are presented. This presentation covers some past experiences and recommends some new insight into this issue.

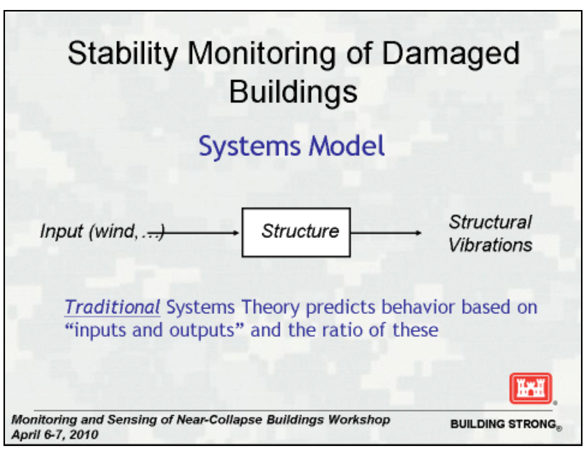
Presentation Slides

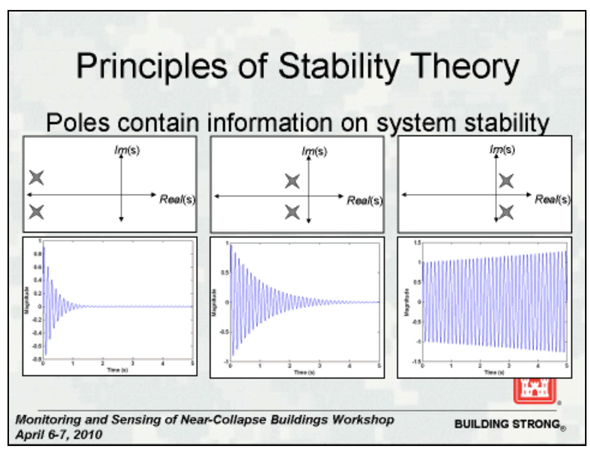




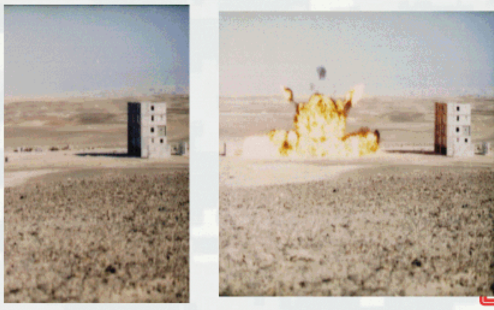




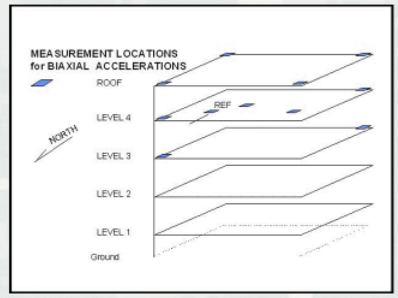




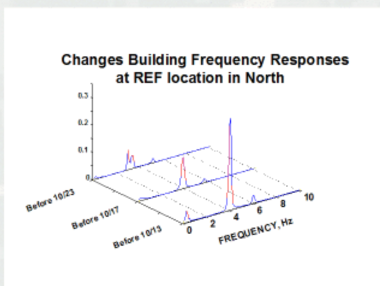
5-story building



5-story building



5-story building



Real-Time Monitoring of Burning Structures

Can it really be done?

Presented by

Zee Duron

Harvey Mudd College

Annual Fire Conference 2009

In Theory, we think that

- Fire produces a random broad-band excitation
- An irreversible process beings at ignition that weakens the structure
- Measured responses can be interpreted and correlated in the context of transient events during burn
- Fire induces structural vibrations
- Fire-induced vibrations can be measured during burn
- Fire-induced vibrations can be used to monitor impending collapse
- *A practical field approach will result if some indication of impending stability loss can be achieved*

Field Experience leads to

- Practical considerations for monitoring structural response
  - Must be independent of structure type, construction materials, or excitation
  - Must provide capability for monitoring response beyond “traditional frequency range of interest”
  - Sensor parameters must be selected for low SNR, high sample rates, and high sensitivities
  - Simplified stability indicator algorithms could work

"Black Box Model"

Traditional Systems Theory predicts behavior based on "inputs and outputs" and the ratio of these.

Not knowing what the system is does not prohibit system characterization.

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Civil Engineers think

- Traditional approaches to structural or earthquake monitoring are limited to frequency ranges defined by dominant structural or ground frequency content.
- Caltech/USGS and the Southern California Seismic Network sample responses at 200 sps
  - The Reagan Medical Center is sampled at 500 sps
- *It is well known that changes in structural frequencies do not track well with damage or impending collapse*

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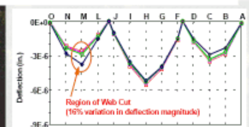
e.g. Sycamore Bridge

$$[H(\omega=0)] = \frac{1}{[K]} = [f] = flexibility$$

$$[f] = \sum_{r=1}^{N}\left[\frac{\{\psi\}_r\{\psi\}_r^T}{M_{A_r}(-\lambda_r)} + \frac{\{\psi\}_r^*\{\psi\}_r^{*T}}{M_{A_r}^*(-\lambda_r^*)}\right]$$

Essentially, the flexibility matrix, [f], may be interpreted as the frequency response function matrix, [H(ω)], at zero frequency [Catbas et. al. 1997].



$$\Delta f_{fundamental} \approx 6\% \quad \Delta wavespeed \approx 38\%$$

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Monitoring Structural Response

Early warning based on "structural response" is not practical

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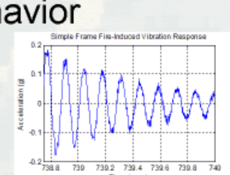
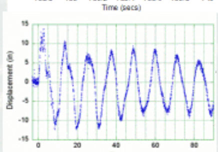
Insights into Characteristic Behavior





oscillatory motion of WTC 2 through image analysis of the moiré patterns on video records – Dr. Butler

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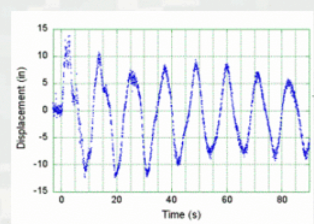
WTC Displacement Record



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Moire Fringes

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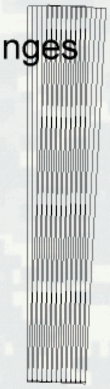
Moire Fringes



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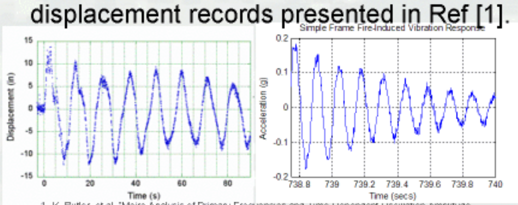
WTC 2 Displacement Record Analysis

- A Moiré analysis of video acquired from WTC 2 has resulted in a series of displacement records presented in Ref [1].



1. K. Butler, et.al, "Moire Analysis of Primary Frequencies and Time-Dependent Oscillation Amplitude Following the Aircraft Impact for WTC 2," NIST NCSTAR 1-5, Appendix K, pp.915-954.

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Can we do better?

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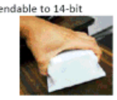
Wireless Fire-Sensor v2

Hardware

- 50% reduction in Original PCB area
- Minimum 2 Hour battery life (estimated)
- Rechargeable Battery
- Optional MicroSD card storage
- One unit fully functional; three more in fabrication
- Wireless L.O.S range: 300ft; Extendable up to 1mile.
- 12-bit resolution over ±1.7g, 5kHz bandwidth; Extendable to 14-bit

Casing

- Preliminary casing designed and constructed
- One-handed design
- Bolt-mount for controlled testing scenarios
- Modular Accelerometer Design



Sensor – Most Critical

- Fire-induced vibrations can have low SNR
- Large civil structures typically produce signals with low SNR
  - A major obstacle to "health monitoring" in the 70's and 80's
  - Advances in instrumentation, computer, and manufacturing technologies in the 90's allows a different approach
- "Dense Instrumentation" can replace sophisticated algorithms and expensive instrumentation for health monitoring purposes
- Low-cost, high sensitivity (V/g), wide bandwidth I/O

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Next Steps

- Algorithm development could continue…
  - Probably not needed for practical field units
  - Wireless systems are being developed
- FEMA fire prevention and safety grant
  - BFRL
  - LA County Fire Department
  - Distribution of wireless systems
  - Database development

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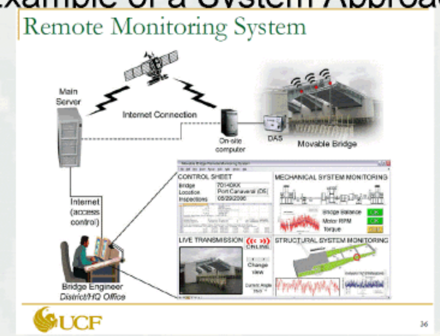
Example of a System Approach



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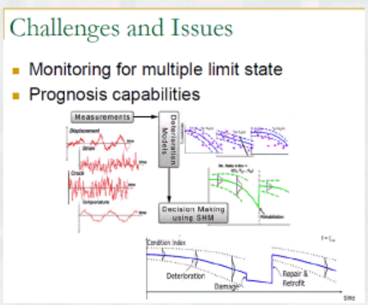

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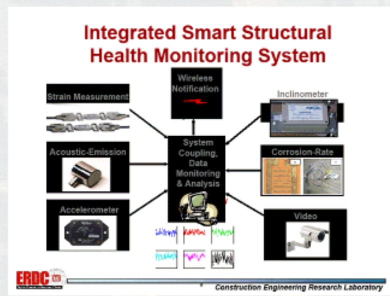
SHM on I-20 Bridge, Vicksburg



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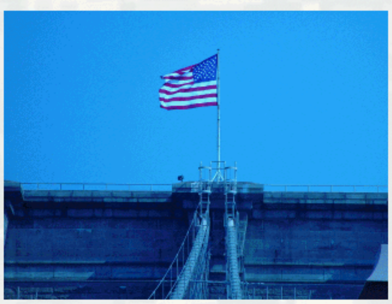

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SESSION 4

EQUIPMENT AND TECHNIQUES

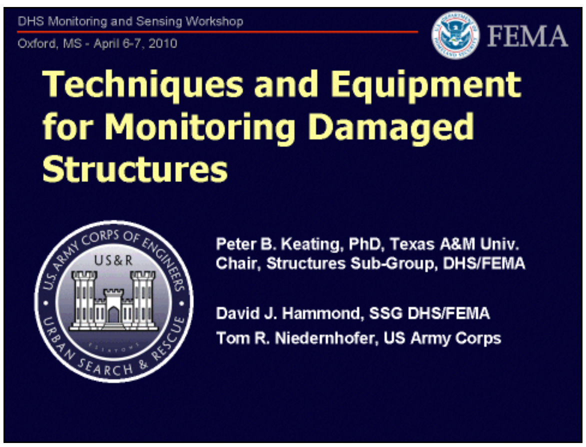
Peter Keating

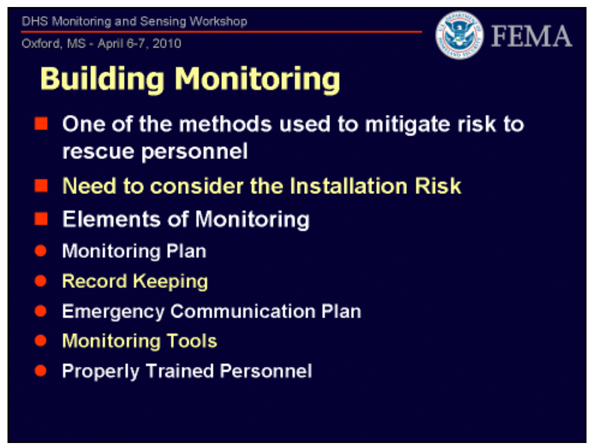
A biography of Dr. Keating can be found on page 34.

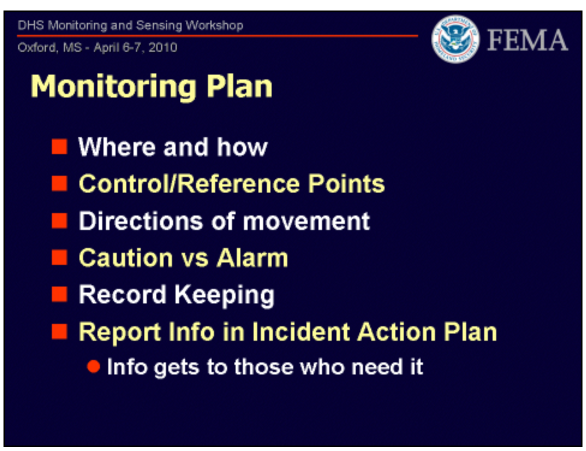
Techniques and Equipment for Monitoring Damaged Structures

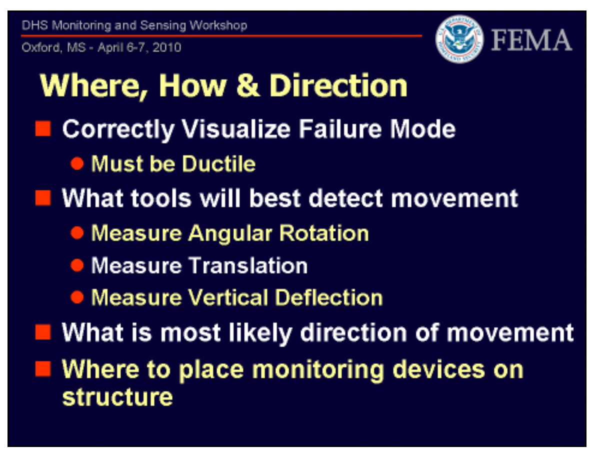
At a collapsed or damaged building incident, search & rescue operations may require monitoring of hazards to help reduce the risk to the rescuers. This is often the case when the hazards to the rescuers cannot be mitigated using other means. Monitoring techniques employed by FEMA Urban Search and Rescue personnel vary in sophistication from a simple plumb to a wireless biaxial tiltmeter system. The technique used by the Rescue Trained Professional Engineer (Structures Specialist) at a particular incident depends on the type of the building and expected collapse behavior, the anticipated length of the rescue operation and the anticipated timing of how the hazard will fail. This presentation describes monitoring techniques used in the Federal Emergency Management Agency Urban Search & Rescue (FEMA US&R) System.

Presentation Slides









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FEMA

Control/Reference Points

- Essential to establish Repeatability
  - Establish Credibility
  - Avoid False Alerts/Alarms
- Selected for Stability
  - Not affected by :
    - Wind
    - Temperature
    - Changes from Debris Removal
    - Changes in Sight Lines

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FEMA

Caution vs Alarm

- Need to know what is "Reasonable" or "Normal" Movement
  - Due to light winds
  - Due to change in Sun Angle
- Only valid is Failure Mode is Ductile
  - Otherwise, No Warning Time
- Levels may change
  - Based on incident's observation history
- Need Effective Warning System
  - See Emergency Comm Plan to follow

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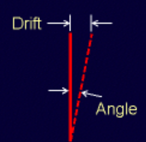
FEMA

Story Drift

Compare Angle Rotation to Story Displacement – in one 12ft story



Story Drift = Lateral Displacement in 1 Story

Angle (deg)	.01	.05	.10	.15	.20	.40	.60	.80
Drift (inch)	.025	.126	.251	.337	.502	1.0	1.51	2.01

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FEMA

Data Interpretation

- Most Challenging Aspect
  - No simple Rules
  - Consider overall context of Bldg & Incident
- Key Factors to Consider
  - Initial Conditions
  - Movement Magnitude & Rate
  - Movement Trend –Cyclic, Monotonic, Step
  - External Influences
- All movement must be considered "In Context"
  - OKC Murrah Bldg – "Normal" was 5/8" in 10 stories

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Reference Movements - Bldgs

- The 1, 2, 3 Rule – Normal "Noise"/ Story
  - Concrete = 1/16" (0.025 deg)
  - Steel = 2/16" (0.05 deg)
  - Wood = 3/16" (0.075 deg)
- Rough estimates only
  - Caused by change in sun angle
  - Caused by light winds
  - Day- night transition

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Reference Movements - Devices

- Plumb bob – Vulnerable to wind
- Crack Gage – Parallax may be an issue
- Smart Level – Resolution is 0.20 deg
- Laser Level – Diameter of Beam
- Total Sta/Theodolite – Depends on quality and stiffness of Tripod Set-up
- WBMS – Resolution is 0.05 deg
  - Software displays to 0.01 deg

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Record Keeping

- Written Records need to be kept of all Monitoring Devices
  - All Monitoring Devices, inc Crack Monitor
  - See next slide for suggested intervals
- Recording System can be setup and kept by IST Structure Spec Staff
  - Each TF Structure Spec should keep own Unit Log including Monitoring Data
  - Need to share data at every shift change, assuming no significant movement (Hand-off)
  - Report Info in IAP, OAP and/or TAP
    - Depends on incident & IST

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Recording Data, Intervals

- Periodically
  - Initially Hourly – Later at longer interval
  - Electronically and/or FEMA Forms
- Discussion at Shift Change
- Following Significant Events
  - Aftershocks
  - Windstorms
  - Shifting of Debris
  - Heavy Equipment – load collisions, etc

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Communication Protocols

- Need to strike a balance between Rapid Notification and Avoidance of False Alarms
  - Alert Threshold must be greater than "Normal", but less than Impending Collapse
- Must be able to Effectively Communicate any Alarm to Leadership
- A pre-determined "Alarm Level" need to be discussed & established with Leaders, so Rapid Response is Facilitated

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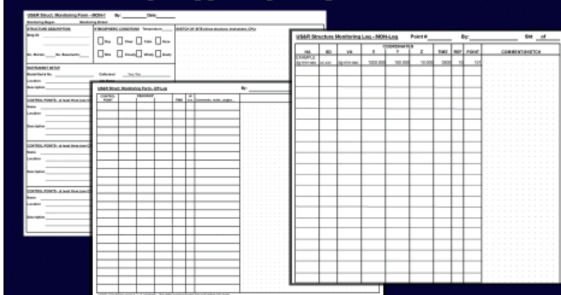
FEMA Monitor Forms



All Monitoring Forms used to hand-off information to the on-coming shifts

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Emergency Comm. Plan

- Effective Warning System
  - For Caution and Alarm Warnings
- Involves Coordination
  - FEMA Task Force Leaders
  - FEMA Incident Support Team
  - Incident Command
- All must understand, and be able to Hear Warning Signals
- All must know their Evacuation Routes, and to Whom they Report

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US&R Monitoring Devices

- Total Station (Theodolite)
  - Reflectorless Total Station
- Electronic Tilt Meter (WBMS)
- Electronic Level
  - SmartLevel & SmartTool
- Laser Levels
- Plumb bob
- Crack measuring devices
- Wind Speed Measuring Devices

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Total Station

- A surveying instrument that measures both angle (horizontal & vertical) and distance
- Uses a pulse laser to measure distance to a reflectorless surface
- Can automatically convert angle and distance measurements into a pre-established X, Y, & Z coordinate system, easy to interpret movements
- Older Theodolites measured only horizontal and vertical angles, difficult to interpret.

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Total Station

- Advantages
  - Observation w/o contacting structure
  - Make Distant Observations
  - Ability to Zoom-In on Structure
  - Observe many points from One Location
- Disadvantages
  - Cost of instrument
    - 5sec Reflectorless Total Sta = $6500
  - Need Trained Operators
  - Readings not Intuitive (Theodolite)
  - Need stable Reference/Control points
    - Difficult establishing aftershock control?
  - Can't Use w/Face Mask

Use of Total Station

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Total Station

- Potentially can be used Poorly and without Reference/Control
- False Movements have been reported at several major incidents
  - Most often as a result of someone inadvertently bumping the tripod, without having an adequate Reference/Control mark system
  - This can lead to a lack of confidence in this very important system
- This is a very effective device that must be used properly

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East Tower
Marginally stable

Monitor from north parking lot using Theodolite + establish link to weather service to warn of winds over 25MPH

Can't establish fall zone - would greatly limit rescue efforts

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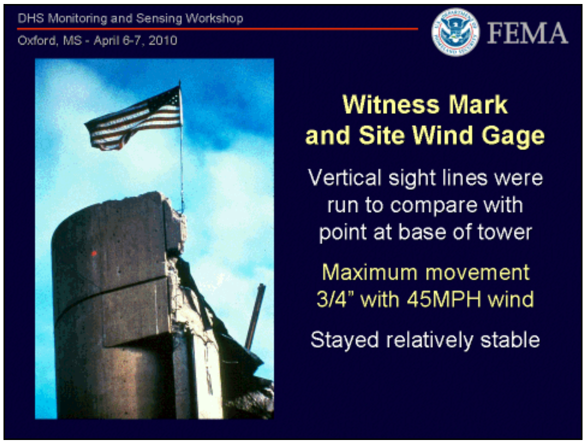
Theodolite in North Parking Lot for East Tower
one also located East of bldg to check Wall Line E



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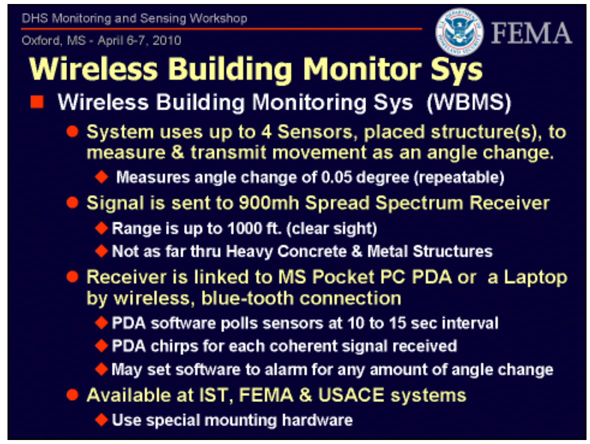
Witness Mark and Site Wind Gage
Vertical sight lines were run to compare with point at base of tower
Maximum movement 3/4" with 45MPH wind
Stayed relatively stable



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Wireless Building Monitor Sys
Wireless Building Monitoring Sys (WBMS)
System uses up to 4 Sensors, placed structure(s), to measure & transmit movement as an angle change.
Measures angle change of 0.05 degree (repeatable)
Signal is sent to 900mh Spread Spectrum Receiver
Range is up to 1000 ft. (clear sight)
Not as far thru Heavy Concrete & Metal Structures
Receiver is linked to MS Pocket PC PDA or a Laptop by wireless, blue-tooth connection
PDA software polls sensors at 10 to 15 sec interval
PDA chirps for each coherent signal received
May set software to alarm for any amount of angle change
Available at IST, FEMA & USACE systems
Use special mounting hardware

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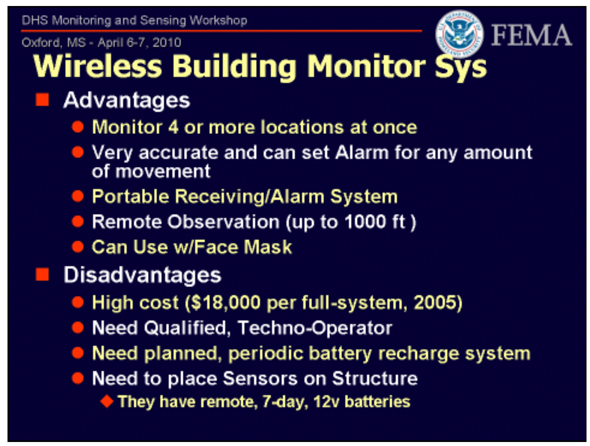
FEMA
Wireless Building Monitor Sys
Sensor
Sensor 4B
Receiver
80lb Case



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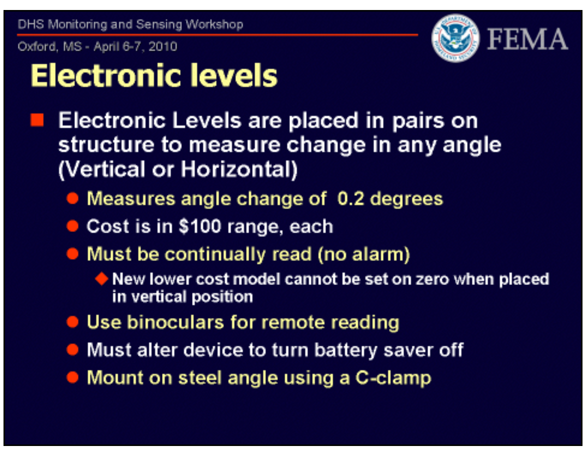
Wireless Building Monitor Sys
Advantages
Monitor 4 or more locations at once
Very accurate and can set Alarm for any amount of movement
Portable Receiving/Alarm System
Remote Observation (up to 1000 ft)
Can Use w/Face Mask
Disadvantages
High cost ($18,000 per full-system, 2005)
Need Qualified, Techno-Operator
Need planned, periodic battery recharge system
Need to place Sensors on Structure
They have remote, 7-day, 12v batteries



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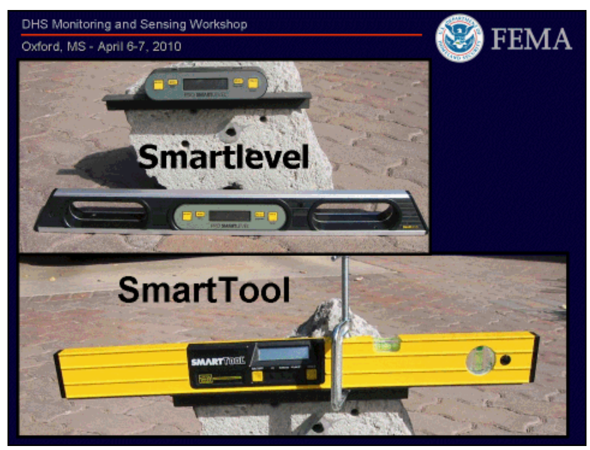
Electronic levels
Electronic Levels are placed in pairs on structure to measure change in any angle (Vertical or Horizontal)
Measures angle change of 0.2 degrees
Cost is in $100 range, each
Must be continually read (no alarm)
New lower cost model cannot be set on zero when placed in vertical position
Use binoculars for remote reading
Must alter device to turn battery saver off
Mount on steel angle using a C-clamp



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Smartlevel
SmartTool

Electronic Levels

- Advantages
  - Low cost
  - Long battery life (about 40 hours)
  - Easy to read
- Disadvantages
  - Not as accurate as WBMS
  - Need to place on structure
  - Need to place 2 in each location to measure angle change in N-S + E-W direction
  - Someone needs to read them – line of sight
  - Need to modify Battery Saver Function

Haiti – Local Monitor

Laser Levels

- Laser Levels - placed on structure to indicate movement by changed position of the light beam on a specified target
  - May measure angle change or lateral/vertical movement
    - Accuracy depends on setup – maybe 0.2 degrees, 1/8"
    - Must be continually read (no alarm)
    - Target should be set in safe area
  - RoboToolz Laser Level
    - Low cost, but less useful
  - Hilti Laser Level - PMP-34
  - Moderate cost w/ lots of extras

RoboToolz Laser Levels

- Cost is $100 each for tri-axial laser
- Battery life is about 14 hours (AAA batteries)
- Mount on steel angle, since device has magnets

Tri-axial

Single

Hilti PMP-34 Laser Level

- GSA cost is $460 each for tri-axial laser
- Battery life is about 40 hours (AA batteries)
- Comes w/ case and several mounting devices
- Self leveling, and has several modes of operation
  - Single, Double, Triple, Self level off, Battery save off
  - 2009 Cache

Laser Levels

- Advantages
  - Low cost
  - Easy to read
- Disadvantages
  - Not as accurate as WBMS
  - Need to place on structure
  - Need to place 2 targets for each location to measure angle change in N-S + E-W direction
  - Someone to read them – line of sight
  - Need to replace batteries
    - Every 12 hrs for RoboToolz
    - Every 40 hrs for Hilti

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Plumb Bob

- Use a Plumb Bob hung from small structure to compare to a point on the ground or pavement
  - Allows one to observe change in a leaning structure
- Advantages
  - inexpensive, easy to use, no special skills (a rock on a string will suffice)
- Disadvantages
  - Requires one to attach to structure, constant observation, not too accurate

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Crack Monitoring

- Draw or sawcut ‘x’ centered on crack
- Use inexpensive ($15) plastic crack monitor that can be placed across a crack

- Spray paint cracked area
- Place shims/cards in cracks
- Inexpensive, easy to read change, but need to be checked (up close) periodically

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Monitor Wind Speed

- Low cost, hand-held devices
  - Kestrel = $100
  - Brunton = $60

- Weather Station w/ remote sensors
  - $150

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Method to Monitor Disaster Site

- P vs S wave - time delay
  - P wave travels faster than S waves
  - If distance from Fault to Site is more than 50km there is opportunity to warn of Aftershocks
- Seismic Trigger deployed at Disaster Site
  - Warns when P wave arrives
  - Destructive S wave arrives later
- Pager System
  - Pagers at disaster site are signaled from sensors at fault that measure Aftershocks

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Trained Monitoring Personnel

- Need properly trained individuals
- TF Structures Spec may be needed elsewhere and not available for monitoring
- Monitoring help is Function of IST StS
  - Pre-scripted Mission Assignment, USACE
  - Local Land Surveyors
  - Other Local Assets
- Proper Training
  - Understand US&R
  - Know what to do with observations
  - Detach from Rescue Operations

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Summary

- Monitoring requires careful planning & the reporting of reliable information
- Collapse must be proceeded by a failure mode that is slow, with measureable deformation
- Devices must be reliable and relatively simple to operate
- Monitoring must integrate into existing US&R protocol and operation

• • •

Blake Rothfuss

Blake D. Rothfuss, P.E., D.WRE, is an Associate with Jacobs Associates, where he specializes in tunnels and underground structural design, construction, stabilization, and rehabilitation. Over his career, Blake has extensive experience in water resources engineering, underground construction, underwater inspection and construction, and managing heavy construction projects. Blake graduated from the University of California, Berkeley, 1983 with a bachelor's degree in Civil Engineering, and Saint Mary's College of California, 2003 with a master's degree in Business.

Blake has been involved in DHS/FEMA Urban Search and Rescue (US&R) since 1990, serving as an original member of the FEMA US&R Training Committee and is currently the Lead Structures Specialist for California Task Force 7 (Sacramento). He is a co-instructor for Structure Specialists Course, Advanced Structures Specialist Course, Structural Collapse Technician Course, and Trench Rescue Course. He has participated in many technical rescue missions including the 2005 Hurricane Katrina Search and Rescue, 2004 Walnut Creek (California) Petroleum Pipeline Explosion, 9/11 attack on the World Trade Center, 2001 California State Capitol attack, 1996 Olympic Summer Games (Atlanta), and 1994 Northridge (California) Earthquake.

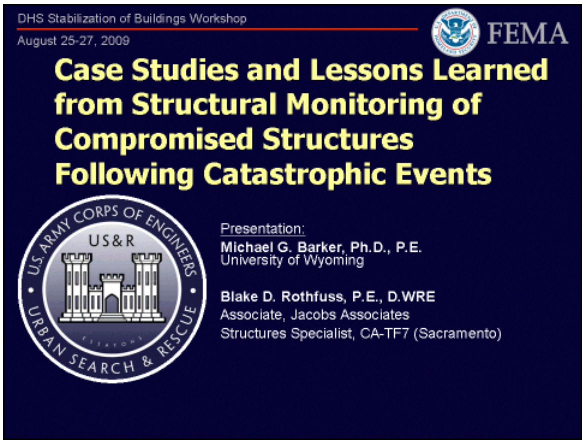
Blake is also a Structures Specialist on the San Francisco Regional US&R Task Force, and a Rescue Engineer/Firefighter with the Moraga-Orinda Fire District.

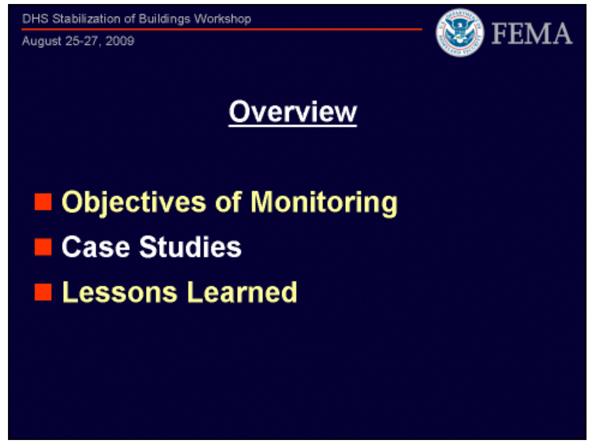
Case Studies and Lessons Learned from Structural Monitoring of Compromised Structures Following Catastrophic Events

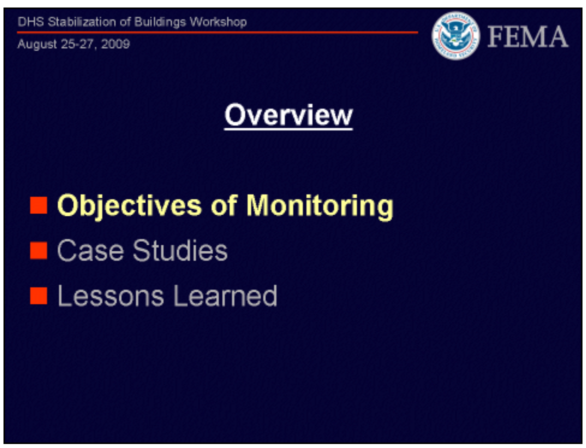
Search and rescue operations within a structure damaged by fire, explosion, construction accident, or earthquake are extremely dangerous due to the compromised structural system, variable loading considerations, and unpredictable structural behavior. Emergency structural monitoring has been utilized at several incidents and yielded different results. Post operational analysis of the structural monitoring activities has identified specific areas for improvement and reinforcement.

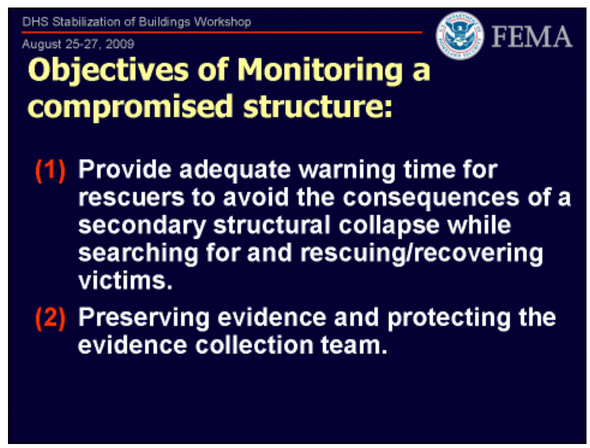
This presentation explores several case studies of past search and rescue incidents that used structural monitoring to help protect rescuers. The past incidents included a fire-damaged masonry warehouse, a precast concrete parking structure damaged during construction, multiple fire-damaged steel framed office buildings, an explosion damaged office building, and an earthquake damaged hotel. This exploration reviews the incidents, incident commander expectations, and monitoring tools and techniques. The lessons learned will emphasize the need for integrated monitoring processes that include communication protocols, failure mode and effects analyses, and movement acceptance criteria, as well as rapidly deployed monitoring tools and techniques.

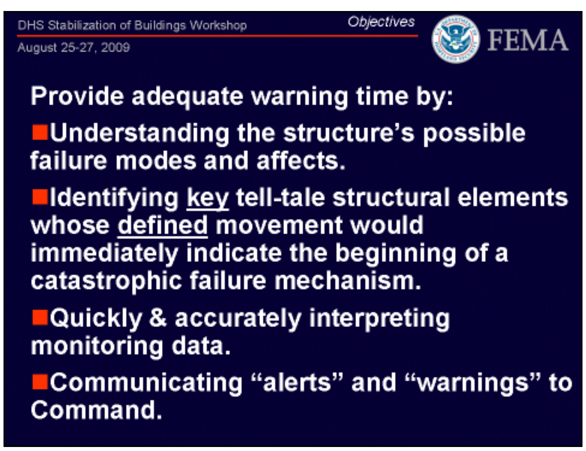
Presentation Slides

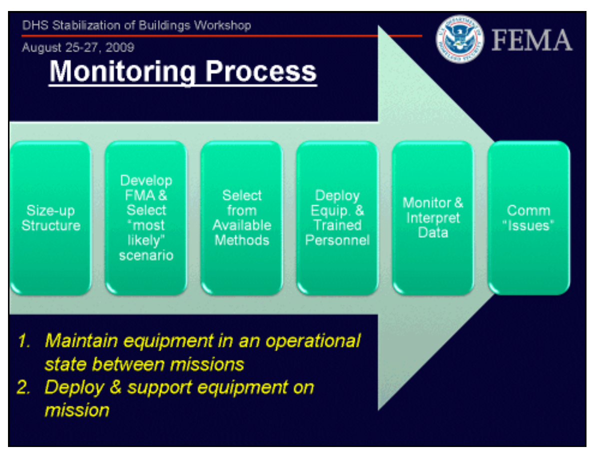












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Overview

- Objectives of Monitoring
- **Case Studies**
- Lessons Learned

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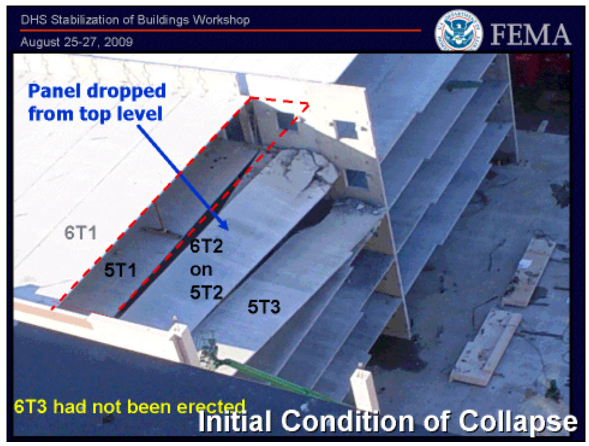
Incident	NIH Parking Garage Collapse Bethesda, Maryland, 2004Nov29
Structure Name	NIH Parking Garage
Cause of collapse	Construction accident
IAP Mode	Recovery
Assignment	Recover construction worker from beneath unstable double tee precast concrete floor section.
Structure description	6-Story parking garage
Structural system, principal	Precast concrete
Monitoring objective	Provide adequate warning time to evacuate personnel
Failure mode & affect	Sudden collapse of supporting walls and corbels.
Techniques & Equipment	



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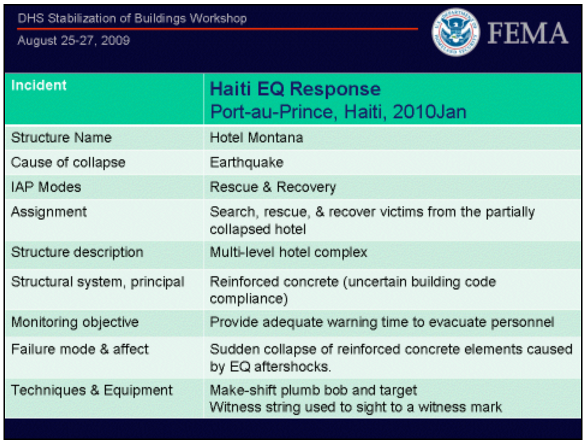
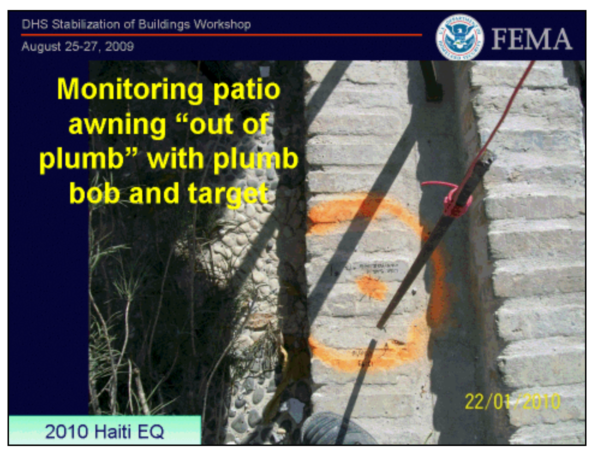
Plus / △

+ Assignment was completed, albeit with a catastrophic structural incident.
+ Structural engineers were actively monitoring the condition of the structure.
△ Concrete micro-cracking wasn't recognized as a potential beam seat/ corbel failure mode.
△ Uncertain that monitoring techniques would have provided adequate warning time.



Incident	Haiti EQ Response Port-au-Prince, Haiti, 2010Jan
Structure Name	Hotel Montana
Cause of collapse	Earthquake
IAP Modes	Rescue & Recovery
Assignment	Search, rescue, & recover victims from the partially collapsed hotel
Structure description	Multi-level hotel complex
Structural system, principal	Reinforced concrete (uncertain building code compliance)
Monitoring objective	Provide adequate warning time to evacuate personnel
Failure mode & affect	Sudden collapse of reinforced concrete elements caused by EQ aftershocks.
Techniques & Equipment	Make-shift plumb bob and target Witness string used to sight to a witness mark



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Plus / △

- + Assignment was completed w/o incident.
- + Improvised low tech monitoring tools were easily deployed and effective.
- + Alert and Warning movements were established qualitatively.
- △ Higher tech monitoring tools (total station & WBMS) were reported to be available, then they weren't. Onsite personnel could not overcome bureaucratic momentum.

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Incident	Worcester Cold Storage Fire Massachusetts, 1999Dec03
Structure Name	Worcester Cold Storage & Warehouse (abandoned)
Cause of collapse	Fire damage
IAP Mode	Recovery
Assignment	Search the partially collapsed warehouse for 2 missing firefighters, presumed dead
Structure description	6 story warehouse with 1 subterranean level
Structural system, principal	Unreinforced brick masonry
Monitoring objective	Provide adequate warning time to evacuate personnel
Failure mode & affect	Sudden collapse of unbraced slender walls caused by high winds and/or loss of masonry integrity
Techniques & Equipment	Theodolite, wind gage, binoculars, & witness line

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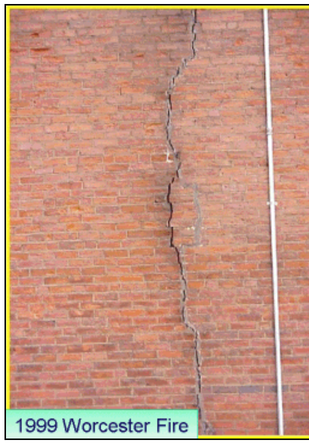
1999 Worcester Fire



1999 Worcester Fire

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Pre-Incident Vertical Pattern Cracking

Considered to be shrinkage cracks and to pre-date fire due to repair indications.

Re-opened by fire.

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1999 Worcester Fire

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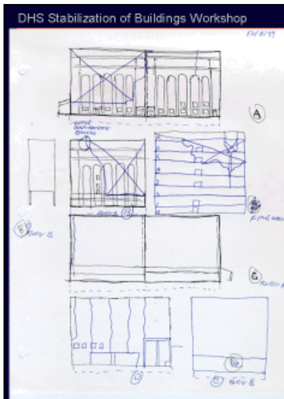
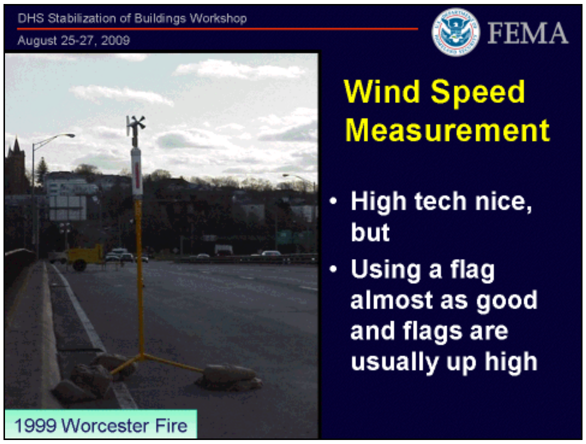


Documentation

1999 Worcester Fire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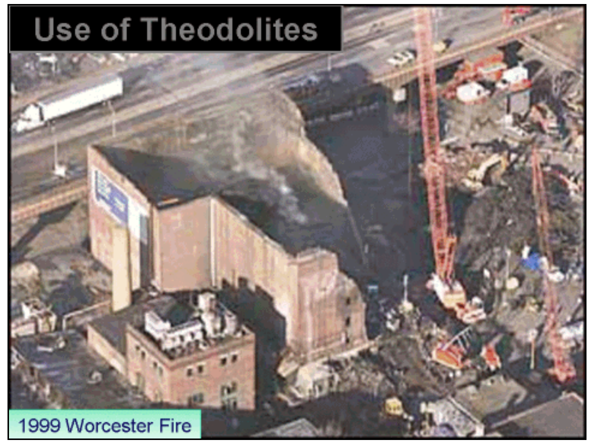
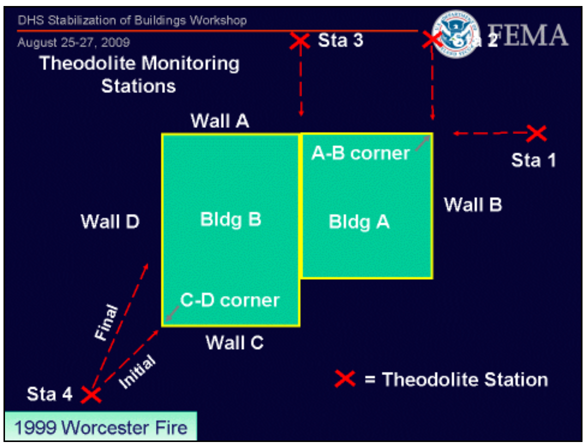
Wind Speed Measurement
• High tech nice, but
• Using a flag almost as good and flags are usually up high
1999 Worcester Fire


Use of Theodolites
1999 Worcester Fire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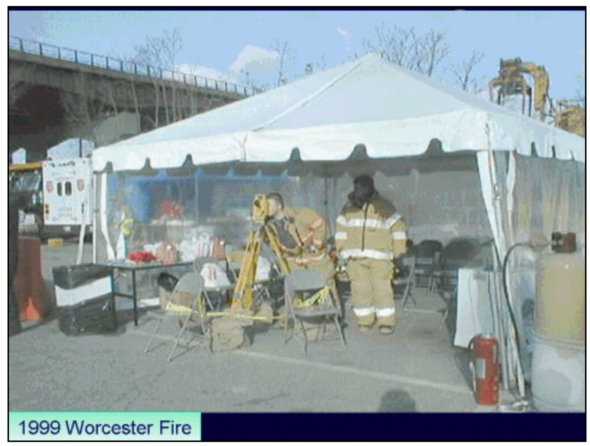
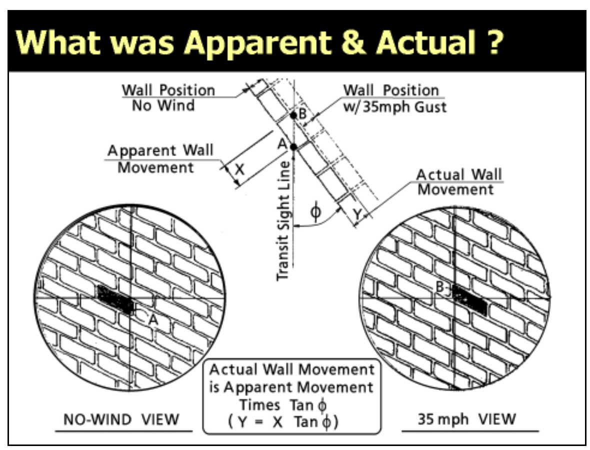
Theodolite Monitoring Stations
Sta 3
Sta 2
Wall A
A-B corner
Sta 1
Wall D
Bldg B
Bldg A
Wall B
C-D corner
Final
Initial
Wall C
Sta 4
= Theodolite Station
1999 Worcester Fire


1999 Worcester Fire


FEMA
Monitoring of C/D Corner Crack
On last day monitoring was switched to Wall D without changing transit location
Movement of 5" was reported
1999 Worcester Fire


What was Apparent & Actual ?
Wall Position No Wind
Wall Position w/35mph Gust
Apparent Wall Movement
Actual Wall Movement
Transit Sight Line
X
Y
A
B
ϕ
Actual Wall Movement is Apparent Movement Times Tan ϕ
(Y = X Tan ϕ)
NO-WIND VIEW
35 mph VIEW

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Plus / △

- + Assignment was completed w/o incident.
- + Recognized pre-incident "indicators"
- + Alert and Warning movements were established quantitatively.
- + Monitoring data was recorded & trended.
- + Low tech monitoring tools were easily deployed and non-techie assistants were easily trained.

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Plus / △

- △ 1:1 ratio of monitoring theodolite to monitoring point consumed 4 instruments.
- △ Fatigue factor of observers watching the same crack with respect to witness line… should have rotated personnel more frequently.
- △ Provide more appropriate weather proof clothing.
- △ Perceived 5" wall movement wasn't accurate.

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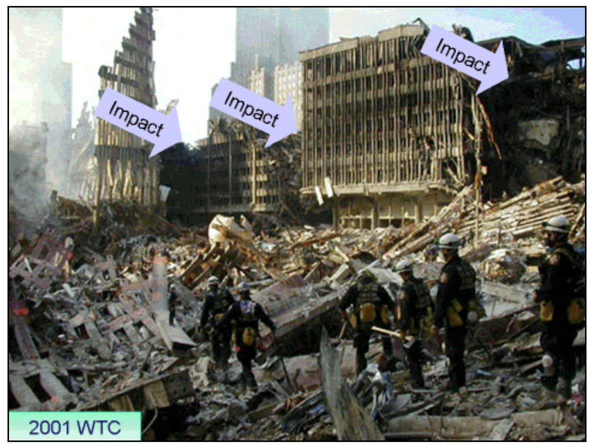
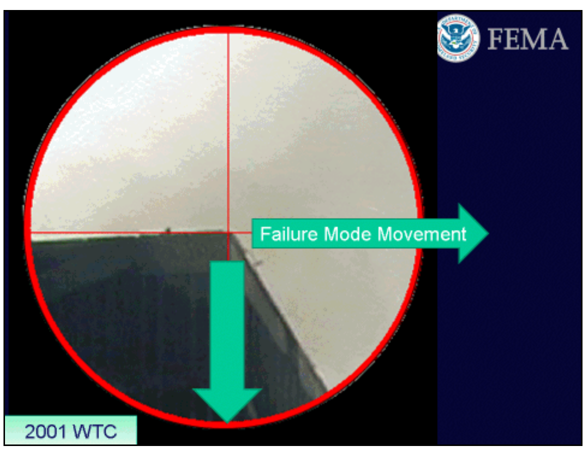
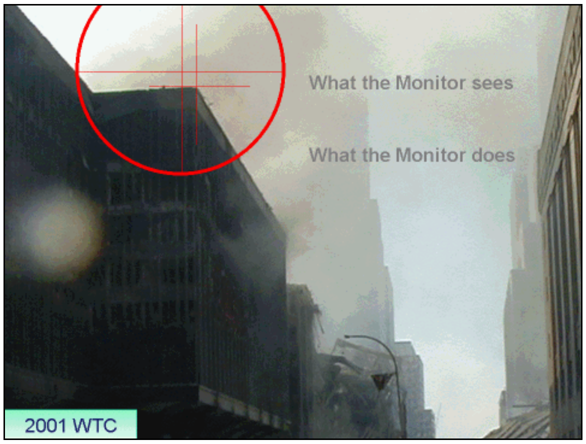
Incident	World Trade Center, 2001Sep
Structure Name	WTC #5 and #6
Cause of collapse	Fire damage & impact loading
IAP Mode	Rescue
Assignment	Search the collapsed areas beneath WTC #5 & #6
Structure description	6 story office building with retail space on 1st floor, and multiple subterranean levels for commuter train access, parking, utilities, and storage.
Structural system, principal	Steel moment resisting frame
Monitoring objective	Provide adequate warning time to evacuate personnel
Failure mode & affect	Slow progressive translation
Techniques & Equipment	Theodolite & witness line







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Plus / △

+ Assignment was completed w/o incident.
+ Monitoring data was recorded & trended.
△ Limited "rules of thumb" for how much movement was TOO MUCH.
△ Theodolite tripod was bumped & instrument indicated (in error) ¼" of movement consistent with FMA.
△ "Warning" signal was given (in error) & entire WTC site was evacuated for 1 hour.

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Overview

- Objectives of Monitoring
- Case Studies
- **Lessons Learned**

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Objectives (Revisited)

(1) Provide adequate warning time for rescuers to avoid the consequences of a secondary structural collapse while searching for and rescuing/recovering victims.

(2) Preserving evidence and protecting the evidence collection team.

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Key Monitoring Learning Points
What's working

Monitoring provides the most warning time where:

- Secondary structural collapse or falling debris is preceded by slow, measurable movement; and,
- Trained personnel operate the monitoring equipment & interpret the data.

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Key Monitoring Learning Points
Opportunities

Monitoring has not provided sufficient warning time where:

- Load-path redundancy is limited;
- Non-ductile or brittle structural materials are involved;
- Demand for trained monitors exceeds the supply of trained monitors; and,
- Movement is not visible to the naked eye.

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Emergency Monitoring Systems
Desirable characteristics

Design & Form Factors

- *One person should be able to carry the system(s) through airport security or over rough terrain.*
- *The system(s) must be weather proof and durable.*
- *The system must be remotely monitored from at least 50 meters distance.*
- *The system must be able to work underground .*

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Emergency Monitoring Systems
Desirable characteristics

Pre-deployment

- *One person should be able to easily maintain the system(s) in an operational "ready to go" mode.*
- *User training should take no longer than 1 hour.*

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Emergency Monitoring Systems
Desirable characteristics

In the Field

- *System installation & calibration must be completed quickly while in the high hazard area.*
- *User ramp-up time must be short and instructions must be easy to understand.*
- *User must be able to perform system troubleshooting.*
- *Batteries must be standard sizes and available in a disaster area or easily resupplied.*

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Questions

• • •

SESSION 5
MODERN SENSING TECHNOLOGIES

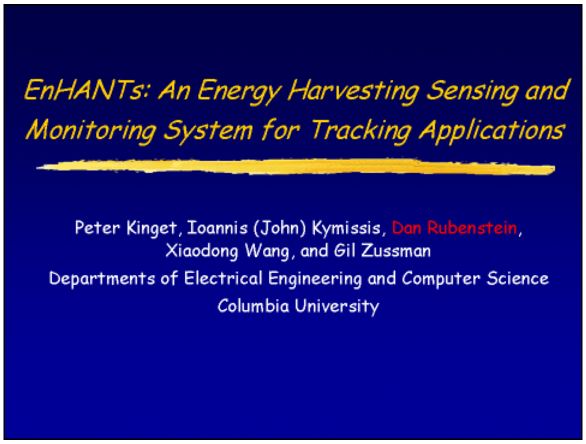
Dan Rubenstein

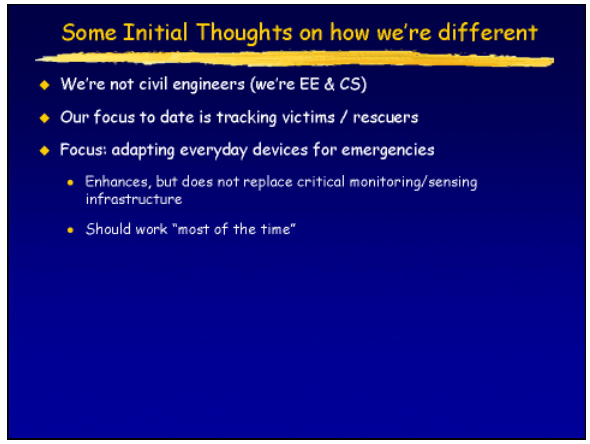
Dr. Dan Rubenstein is an Associate Professor in the Department of Computer Science at Columbia University. He received a B.S. degree in mathematics from MIT, an M.A. in math from UCLA, and a Ph.D. in computer science from the University of Massachusetts, Amherst. His research interests are in network technologies, applications, and performance analysis, with a recent emphasis on resilient, secure, and ultra-low power networking. He is an editor for IEEE/ACM Transactions on Networking, and has received an NSF CAREER Award, IBM Faculty Award, the Best Student Paper award from the ACM SIGMETRICS 2000 conference, and Best Paper awards from the IEEE ICNP 2003 Conference and ACM CoNext 2008 Conference.

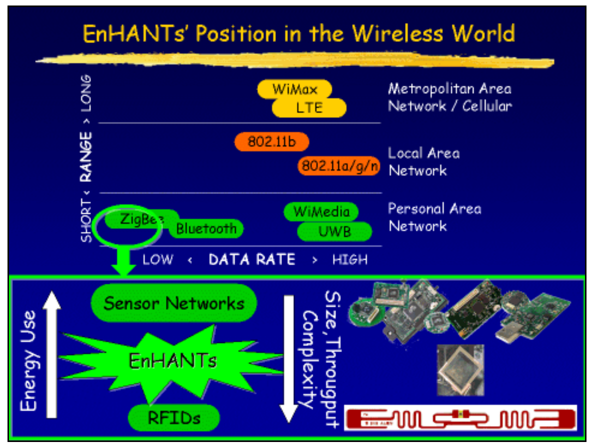
EnHANTs: An Energy Harvesting Sensing and Monitoring System for Tracking Applications

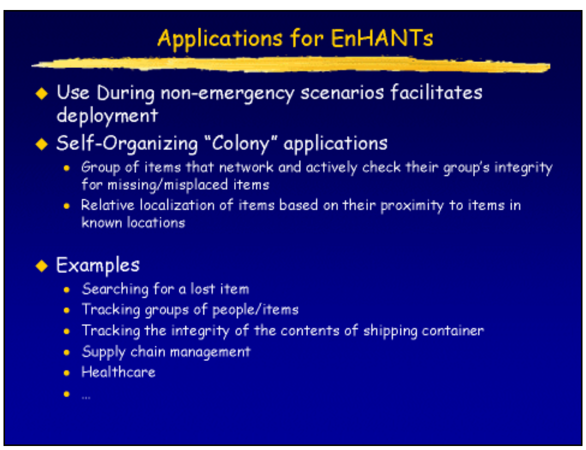
In this program we are developing Energy-Harvesting Active Networked Tags (EnHANTs). EnHANTs are small, flexible, and self-reliant devices that harvest their own energy and can be attached to objects that are traditionally not networked providing the infrastructure for various novel tracking applications. Examples of these applications include locating misplaced items, continuous monitoring of objects, and determining the location of disaster survivors. The objective of the project is to design hardware, algorithms, and software to enable the realization of EnHANTs. The efficiency of commercially available hardware and committee-based communication protocols is inadequate to realize this goal, and it is only possible to create an entirely self-powered system by re-engineering the hardware, software, and protocol layers of the system for this purpose. We are leveraging the resources of several groups at Columbia and taking advantage of advances in ultra-low-power wireless communications, ultra-wideband (UWB) circuit design, new energy aware peer-to-peer networking architectures, and organic semiconductor-based energy harvesting techniques to enable the realization of EnHANTs using fully custom hardware in the near future. This presentation outlines the concept, components, and progress made in the EnHANTs program and the opportunities that the platform presents for disaster recovery applications both on its current hardware platforms and in future iterations.

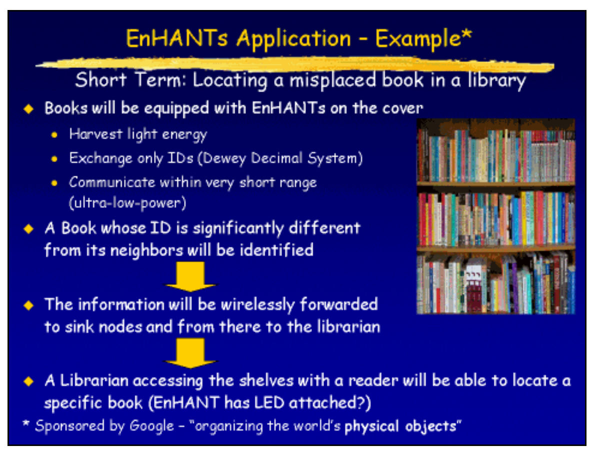
Presentation Slides

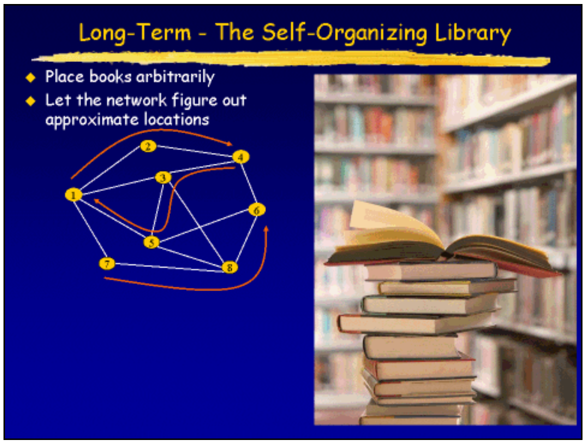




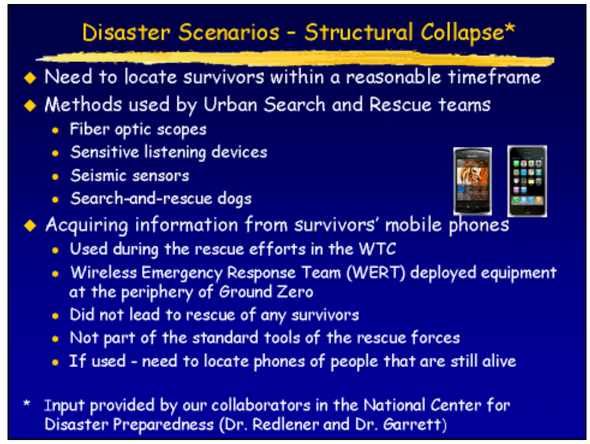




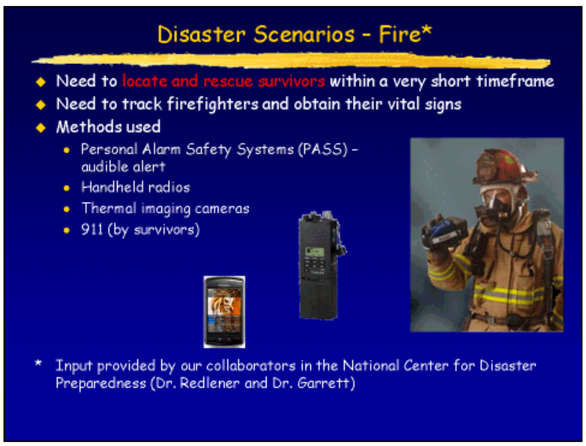




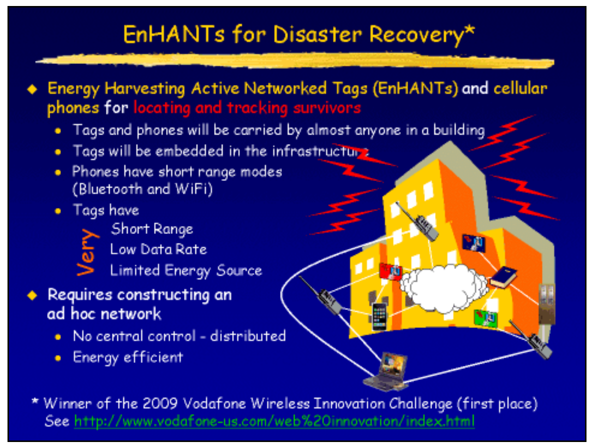
Long-Term - The Self-Organizing Library
Place books arbitrarily
Let the network figure out approximate locations
1
2
3
4
5
6
7
8



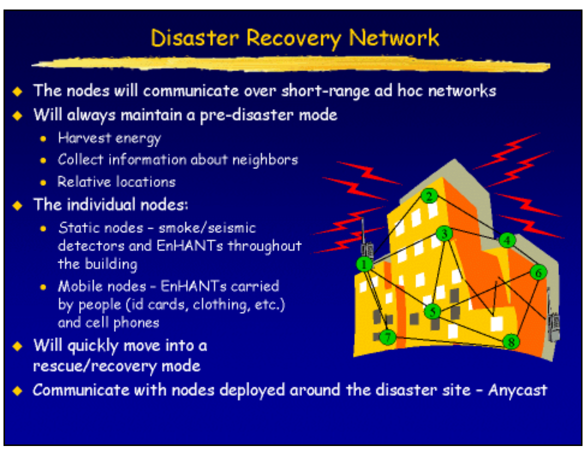
Disaster Scenarios - Structural Collapse*
Need to locate survivors within a reasonable timeframe
Methods used by Urban Search and Rescue teams
Fiber optic scopes
Sensitive listening devices
Seismic sensors
Search-and-rescue dogs
Acquiring information from survivors' mobile phones
Used during the rescue efforts in the WTC
Wireless Emergency Response Team (WERT) deployed equipment at the periphery of Ground Zero
Did not lead to rescue of any survivors
Not part of the standard tools of the rescue forces
If used - need to locate phones of people that are still alive
* Input provided by our collaborators in the National Center for Disaster Preparedness (Dr. Redlener and Dr. Garrett)



Disaster Scenarios - Fire*
Need to locate and rescue survivors within a very short timeframe
Need to track firefighters and obtain their vital signs
Methods used
Personal Alarm Safety Systems (PASS) - audible alert
Handheld radios
Thermal imaging cameras
911 (by survivors)
* Input provided by our collaborators in the National Center for Disaster Preparedness (Dr. Redlener and Dr. Garrett)



EnHANTs for Disaster Recovery*
Energy Harvesting Active Networked Tags (EnHANTs) and cellular phones for locating and tracking survivors
Tags and phones will be carried by almost anyone in a building
Tags will be embedded in the infrastructure
Phones have short range modes (Bluetooth and WiFi)
Tags have
Very
Short Range
Low Data Rate
Limited Energy Source
Requires constructing an ad hoc network
No central control - distributed
Energy efficient
* Winner of the 2009 Vodafone Wireless Innovation Challenge (first place)
See http://www.vodafone-us.com/web%20innovation/index.html



Disaster Recovery Network
The nodes will communicate over short-range ad hoc networks
Will always maintain a pre-disaster mode
Harvest energy
Collect information about neighbors
Relative locations
The individual nodes:
Static nodes - smoke/seismic detectors and EnHANTs throughout the building
Mobile nodes - EnHANTs carried by people (id cards, clothing, etc.) and cell phones
Will quickly move into a rescue/recovery mode
Communicate with nodes deployed around the disaster site - Anycast
1
2
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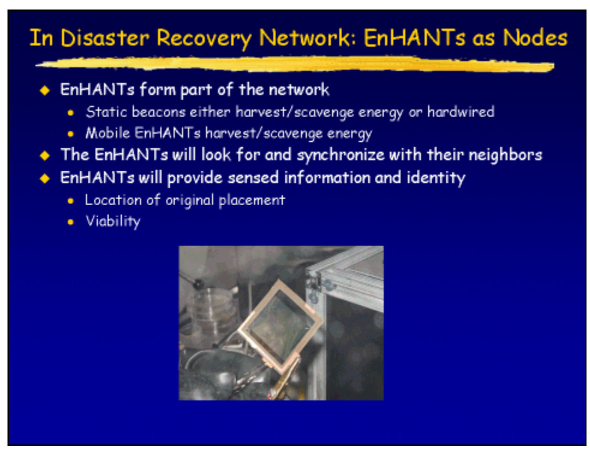
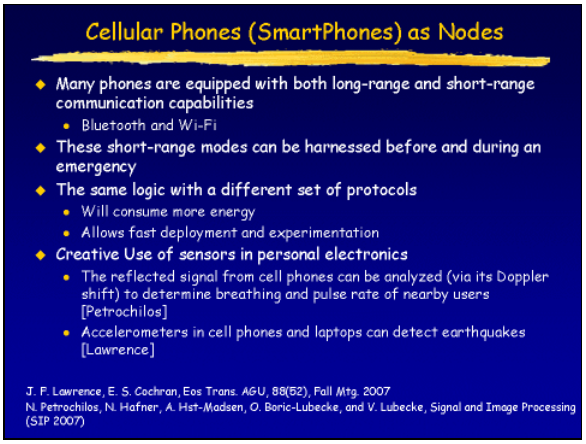
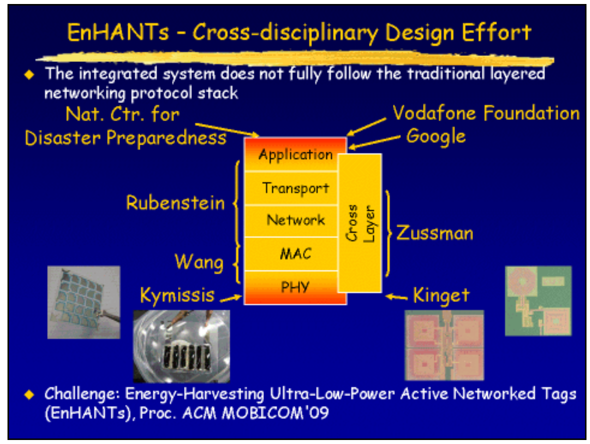


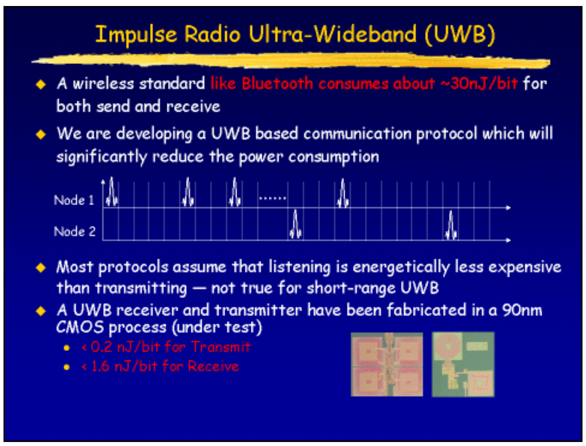
In Disaster Recovery Network: EnHANTs as Nodes
EnHANTs form part of the network
Static beacons either harvest/scavenge energy or hardwired
Mobile EnHANTs harvest/scavenge energy
The EnHANTs will look for and synchronize with their neighbors
EnHANTs will provide sensed information and identity
Location of original placement
Viability



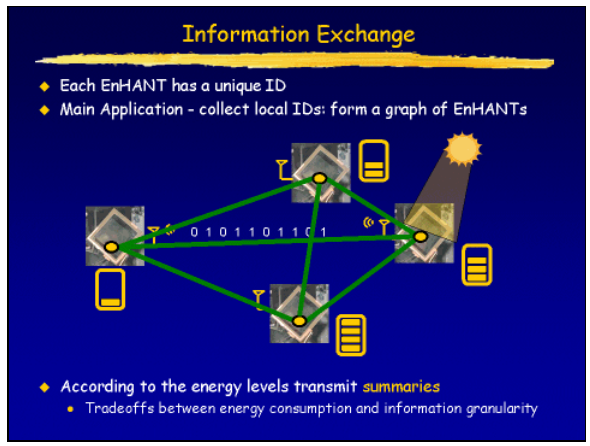
Cellular Phones (SmartPhones) as Nodes
Many phones are equipped with both long-range and short-range communication capabilities
Bluetooth and Wi-Fi
These short-range modes can be harnessed before and during an emergency
The same logic with a different set of protocols
Will consume more energy
Allows fast deployment and experimentation
Creative Use of sensors in personal electronics
The reflected signal from cell phones can be analyzed (via its Doppler shift) to determine breathing and pulse rate of nearby users [Petrochilos]
Accelerometers in cell phones and laptops can detect earthquakes [Lawrence]
J. F. Lawrence, E. S. Cochran, Eos Trans. AGU, 88(52), Fall Mtg. 2007
N. Petrochilos, N. Hafner, A. Hst-Madsen, O. Boric-Lubecke, and V. Lubecke, Signal and Image Processing (SIP 2007)



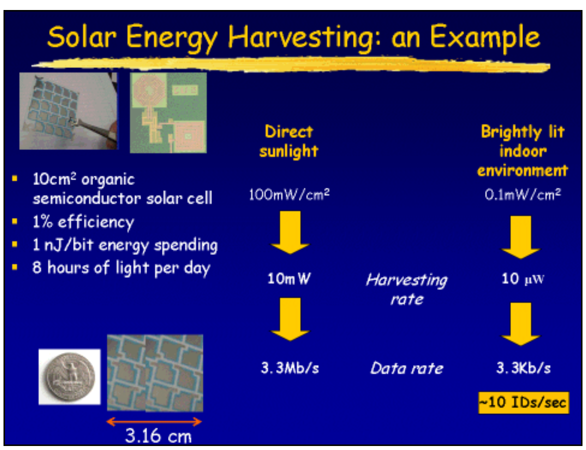
EnHANTs - Cross-disciplinary Design Effort
The integrated system does not fully follow the traditional layered networking protocol stack
Nat. Ctr. for Disaster Preparedness
Vodafone Foundation
Google
Application
Transport
Network
MAC
PHY
Cross Layer
Rubenstein
Wang
Kymissis
Zussman
Kinget
Challenge: Energy-Harvesting Ultra-Low-Power Active Networked Tags (EnHANTs), Proc. ACM MOBICOM'09



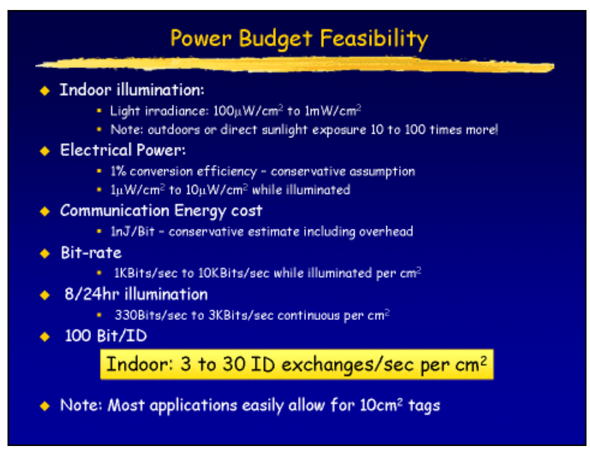
Impulse Radio Ultra-Wideband (UWB)
A wireless standard like Bluetooth consumes about ~30nJ/bit for both send and receive
We are developing a UWB based communication protocol which will significantly reduce the power consumption
Node 1
Node 2
Most protocols assume that listening is energetically less expensive than transmitting — not true for short-range UWB
A UWB receiver and transmitter have been fabricated in a 90nm CMOS process (under test)
< 0.2 nJ/bit for Transmit
< 1.6 nJ/bit for Receive



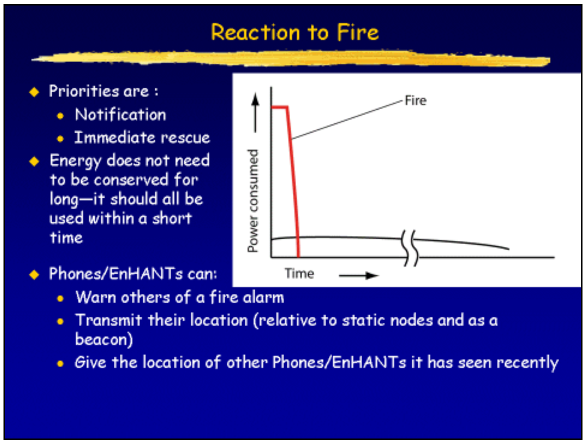
Information Exchange
Each EnHANT has a unique ID
Main Application - collect local IDs: form a graph of EnHANTs
0 1 0 1 1 0 1 1 0 1
According to the energy levels transmit summaries
Tradeoffs between energy consumption and information granularity

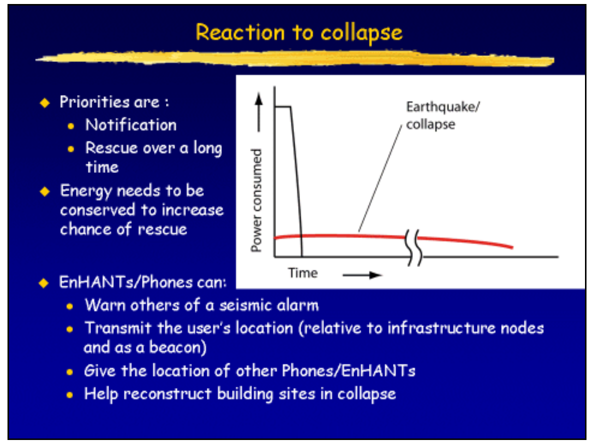


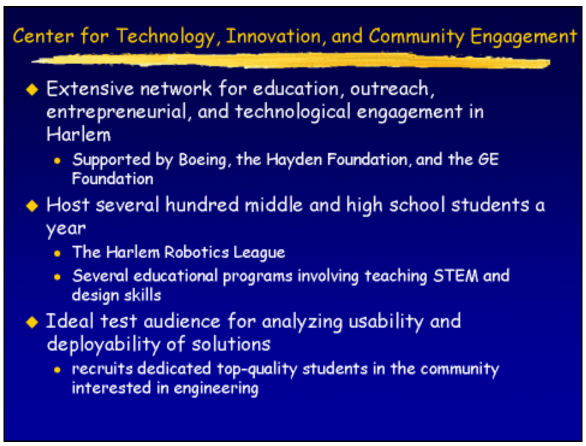
Solar Energy Harvesting: an Example
10cm² organic semiconductor solar cell
1% efficiency
1 nJ/bit energy spending
8 hours of light per day
Direct sunlight
Brightly lit indoor environment
100mW/cm²
0.1mW/cm²
10mW
Harvesting rate
10 µW
3.3Mb/s
Data rate
3.3Kb/s
~10 IDs/sec
3.16 cm

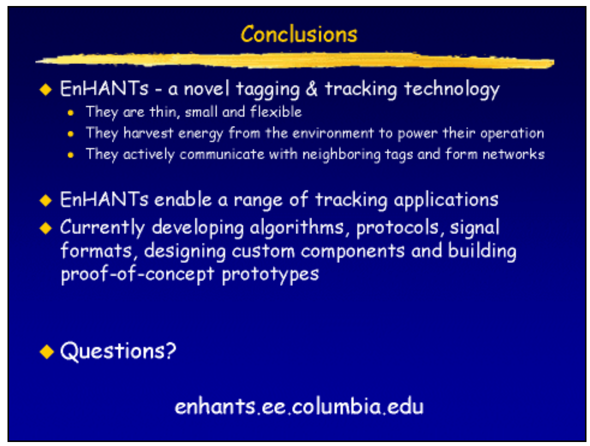


Power Budget Feasibility
Indoor illumination:
Light irradiance: 100µW/cm² to 1mW/cm²
Note: outdoors or direct sunlight exposure 10 to 100 times more!
Electrical Power:
1% conversion efficiency - conservative assumption
1µW/cm² to 10µW/cm² while illuminated
Communication Energy cost
1nJ/Bit - conservative estimate including overhead
Bit-rate
1KBits/sec to 10KBits/sec while illuminated per cm²
8/24hr illumination
330Bits/sec to 3KBits/sec continuous per cm²
100 Bit/ID
Indoor: 3 to 30 ID exchanges/sec per cm²
Note: Most applications easily allow for 10cm² tags









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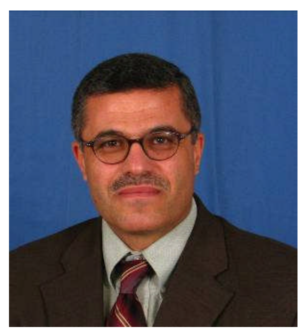
Atef Elsherbeni



Dr. Atef Elsherbeni is a Professor of Electrical Engineering and Associate Dean at the University of Mississippi. He has conducted research that contributed to the scattering and diffraction by dielectric and metal objects, analysis of antennas, passive and active microwave devices, interactions of electromagnetic waves with human body, RFID and sensors, field visualization and software development for EM education, antenna and material properties measurements, and hardware and software acceleration of finite-difference time-domain (FDTD) and finite-difference frequency-domain (FDFD) methods. Dr. Elsherbeni is a Fellow IEEE, a Fellow of ACES, the Editor-in-Chief for ACES Journal, and an Associate Editor to the Radio Science Journal.

Dr. Elsherbeni is the coauthor of the book "The Finite Difference Time Domain Method for Electromagnetics with MATLAB Simulations," SciTech 2009, the book "Antenna Design and Visualization Using Matlab," SciTech, 2006, the book "MATLAB Simulations for Radar Systems Design," CRC Press, 2003, the book "Electromagnetic Scattering Using the Iterative

Multiregion Technique," Morgan & Claypool, 2007, the book "Electromagnetics and Antenna Optimization using Taguchi's Method," Morgan & Claypool, 2007, and the main author of the chapters "Handheld Antennas" and "The Finite Difference Time Domain Technique for Microstrip Antennas" in Handbook of Antennas in Wireless Communications, CRC Press, 2001.

Millimeter Wave Reflectarray Technology for High-Resolution See-Through-Wall Imaging Systems

See-through-wall (STW) imaging systems have great potentials in many applications for enhancing the homeland security such as airport security check. In monitoring and sensing of near-collapse buildings, STW imaging systems are also desirable because it can obtain the images of both static and moving objects inside dangerous buildings without physically entering them.

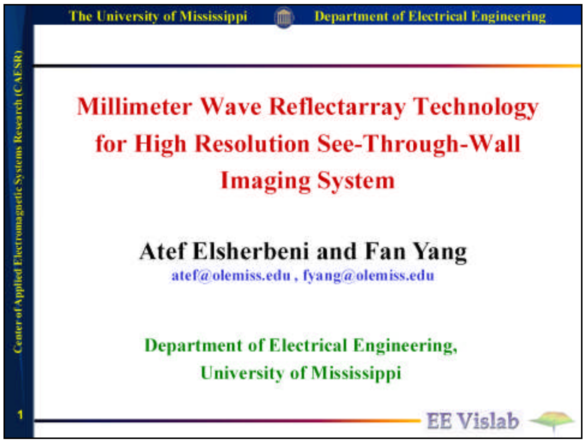
STW imaging systems have used different frequency bands, and the millimeter-wave frequency band is a good option because it can provide a high image resolution as well as a wide bandwidth. High gain antennas are required in these systems for the electromagnetic wave to penetrate through walls. Instead of bulky parabolic reflectors or complex array antennas, we propose to use the reflectarray antennas for STW imaging systems. The reflectarray antennas have low-profile, low-mass, and high radiation efficiency. In addition, their sizes are compact at mm-wave frequency band. Therefore, it is an excellent candidate for mm-wave STW imaging systems.

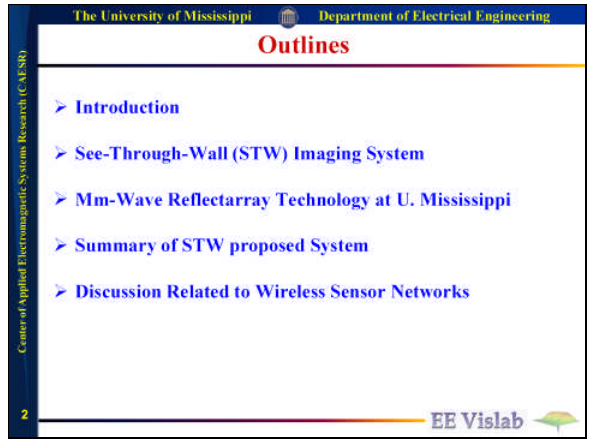
Based on the support from the National Aeronautics and Space Administration (NASA), the authors' group at The University of Mississippi has been working on the analysis, design, fabrication, and testing of reflectarray antennas and is one of the leading research groups in the world. We have made a number of important achievements in this area, including:

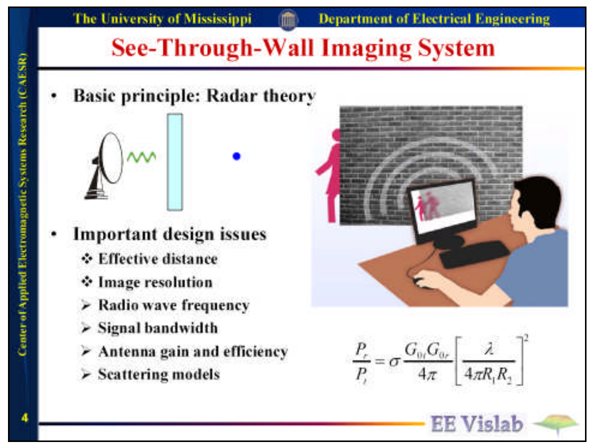
- Accurate and efficient analysis and synthesis methods for reflectarrays;
- Wideband and multi-band reflectarray designs;
- Reflectarrays with multiple radiation beams;
- THz/optic reflectarray concepts.

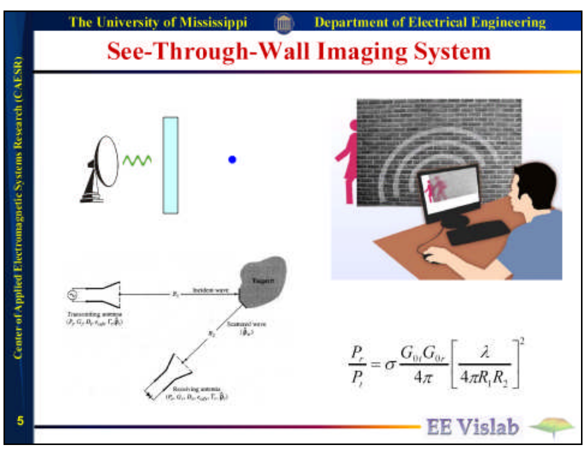
These achievements have established a solid foundation to implement the reflectarray antennas into advanced mm-wave STW imaging systems. With the enhanced penetration capability and image resolution, the mm-wave STW imaging systems will find various applications in monitoring and sensing of near-collapse buildings.

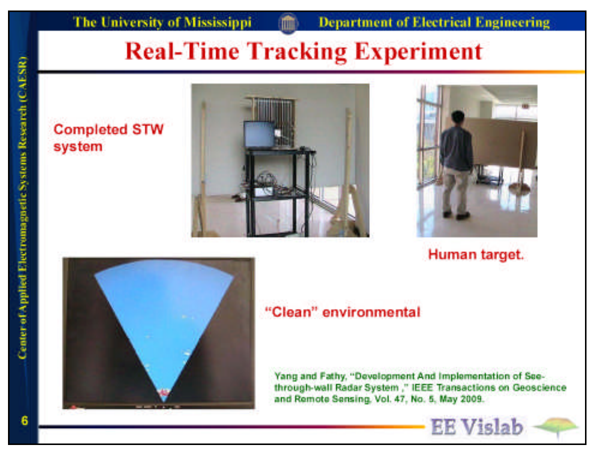
Presentation Slides












The University of Mississippi
Department of Electrical Engineering
Real-Time Traces of Moving Target.
Moving human target.
Yang and Fathy, "Development And Implementation of See-through-wall Radar System," IEEE Transactions on Geoscience and Remote Sensing, Vol. 47, No. 5, May 2009.
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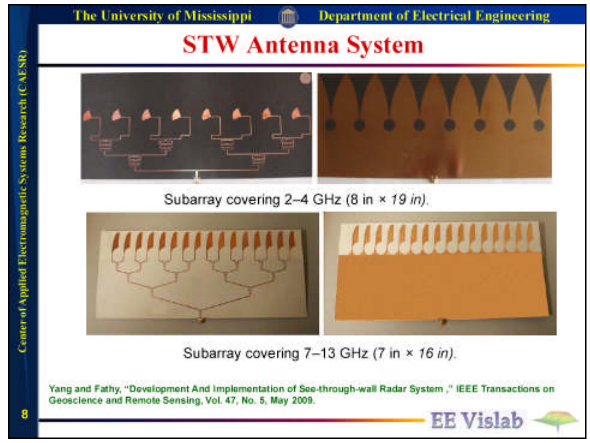
The University of Mississippi
Department of Electrical Engineering
STW Antenna System
Subarray covering 2–4 GHz (8 in × 19 in).
Subarray covering 7–13 GHz (7 in × 16 in).
Yang and Fathy, "Development And Implementation of See-through-wall Radar System," IEEE Transactions on Geoscience and Remote Sensing, Vol. 47, No. 5, May 2009.
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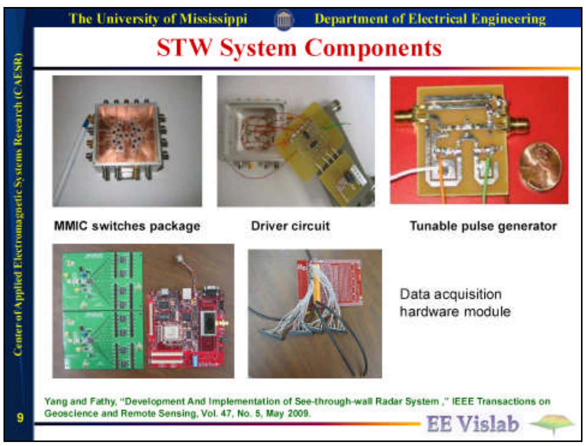
The University of Mississippi
Department of Electrical Engineering
STW System Components
MMIC switches package
Driver circuit
Tunable pulse generator
Data acquisition hardware module
Yang and Fathy, "Development And Implementation of See-through-wall Radar System," IEEE Transactions on Geoscience and Remote Sensing, Vol. 47, No. 5, May 2009.
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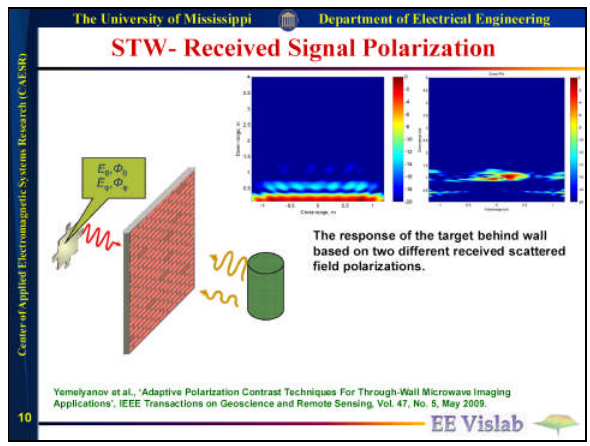
The University of Mississippi
Department of Electrical Engineering
STW- Received Signal Polarization
The response of the target behind wall based on two different received scattered field polarizations.
Yemelyanov et al., 'Adaptive Polarization Contrast Techniques For Through-Wall Microwave Imaging Applications', IEEE Transactions on Geoscience and Remote Sensing, Vol. 47, No. 5, May 2009.
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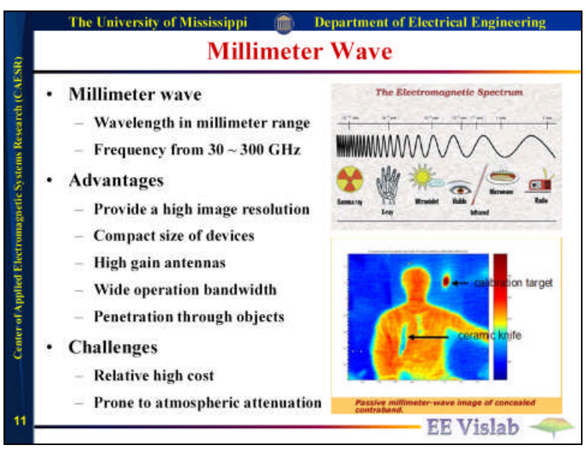
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Department of Electrical Engineering
Millimeter Wave
• Millimeter wave
– Wavelength in millimeter range
– Frequency from 30 ~ 300 GHz
• Advantages
– Provide a high image resolution
– Compact size of devices
– High gain antennas
– Wide operation bandwidth
– Penetration through objects
• Challenges
– Relative high cost
– Prone to atmospheric attenuation
The Electromagnetic Spectrum
calibration target
ceramic knife
Passive millimeter-wave image of concealed contraband.
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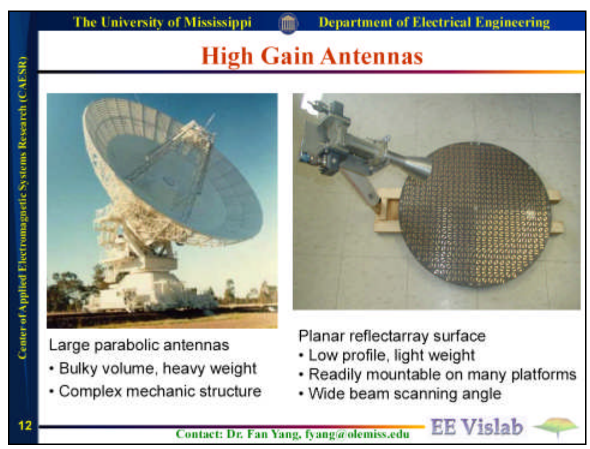
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Department of Electrical Engineering
High Gain Antennas
Large parabolic antennas
• Bulky volume, heavy weight
• Complex mechanic structure
Planar reflectarray surface
• Low profile, light weight
• Readily mountable on many platforms
• Wide beam scanning angle
Contact: Dr. Fan Yang, fyang@olemiss.edu
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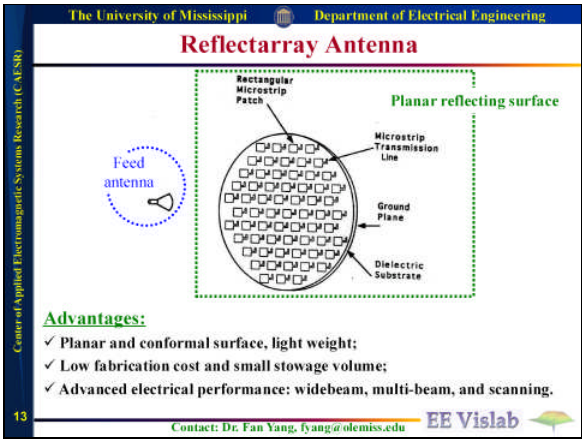

The University of Mississippi
Department of Electrical Engineering
Reflectarray Antenna
Rectangular Microstrip Patch
Planar reflecting surface
Microstrip Transmission Line
Feed antenna
Ground Plane
Dielectric Substrate
Advantages:
✓ Planar and conformal surface, light weight;
✓ Low fabrication cost and small stowage volume;
✓ Advanced electrical performance: widebeam, multi-beam, and scanning.
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Contact: Dr. Fan Yang, fyang@olemiss.edu
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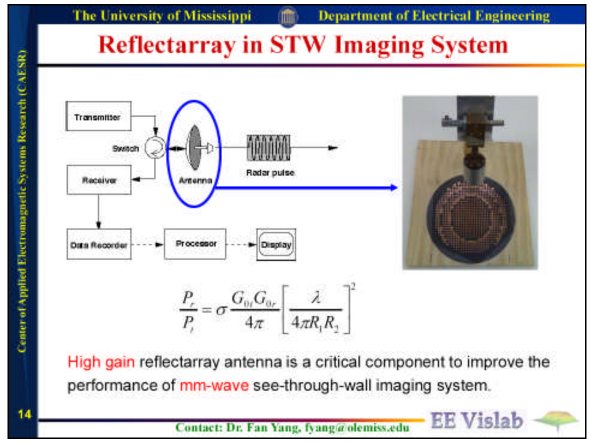

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Department of Electrical Engineering
Reflectarray in STW Imaging System
Transmitter
Switch
Receiver
Antenna
Radar pulse
Data Recorder
Processor
Display
$\frac{P_r}{P_t} = \sigma \frac{G_{0t}G_{0r}}{4\pi}\left[\frac{\lambda}{4\pi R_1 R_2}\right]^2$
High gain reflectarray antenna is a critical component to improve the performance of mm-wave see-through-wall imaging system.
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Contact: Dr. Fan Yang, fyang@olemiss.edu
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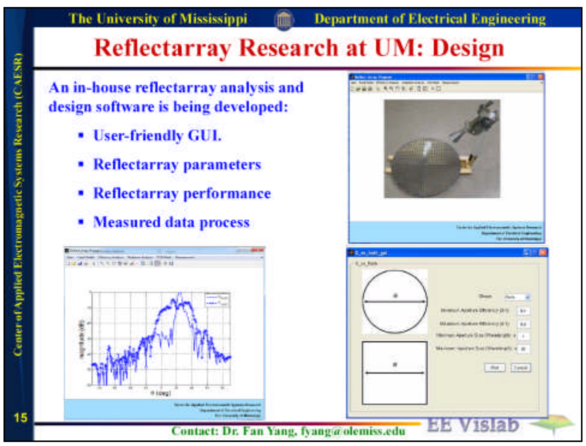

The University of Mississippi
Department of Electrical Engineering
Reflectarray Research at UM: Design
An in-house reflectarray analysis and design software is being developed:
▪ User-friendly GUI.
▪ Reflectarray parameters
▪ Reflectarray performance
▪ Measured data process
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Contact: Dr. Fan Yang, fyang@olemiss.edu
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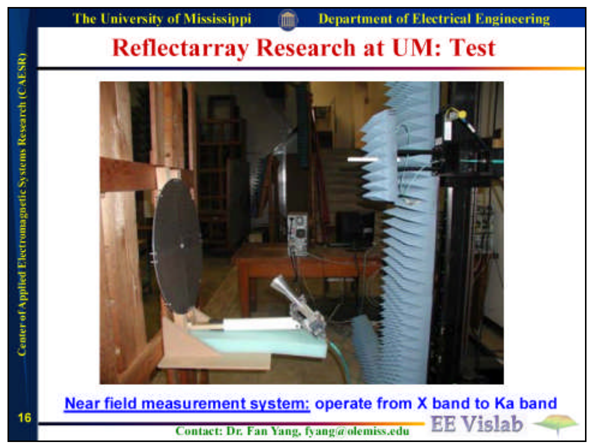

The University of Mississippi
Department of Electrical Engineering
Reflectarray Research at UM: Test
Near field measurement system: operate from X band to Ka band
Center of Applied Electromagnetic Systems Research (CAESR)
16
Contact: Dr. Fan Yang, fyang@olemiss.edu
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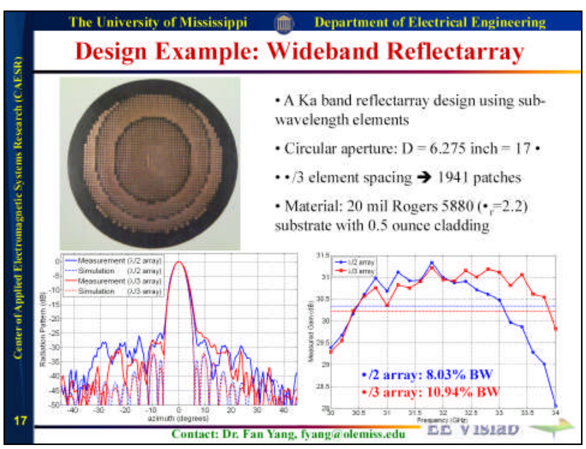

The University of Mississippi
Department of Electrical Engineering
Design Example: Wideband Reflectarray
• A Ka band reflectarray design using sub-wavelength elements
• Circular aperture: D = 6.275 inch = 17 •
• •/3 element spacing ➔ 1941 patches
• Material: 20 mil Rogers 5880 (•r=2.2) substrate with 0.5 ounce cladding
Measurement (λ/2 array)
Simulation (λ/2 array)
Measurement (λ/3 array)
Simulation (λ/3 array)
Radiation Pattern (dB)
azimuth (degrees)
Measured Gain (dB)
Frequency (GHz)
•/2 array: 8.03% BW
•/3 array: 10.94% BW
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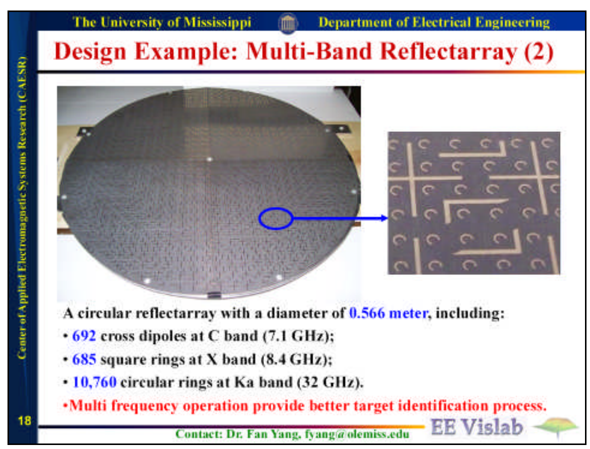

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Design Example: Multi-Band Reflectarray (2)
A circular reflectarray with a diameter of 0.566 meter, including:
• 692 cross dipoles at C band (7.1 GHz);
• 685 square rings at X band (8.4 GHz);
• 10,760 circular rings at Ka band (32 GHz).
•Multi frequency operation provide better target identification process.
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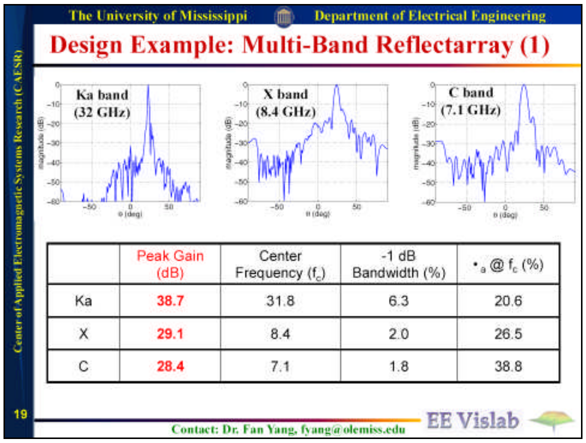
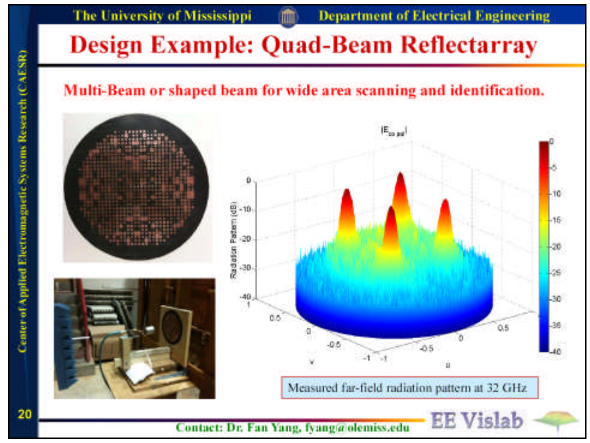
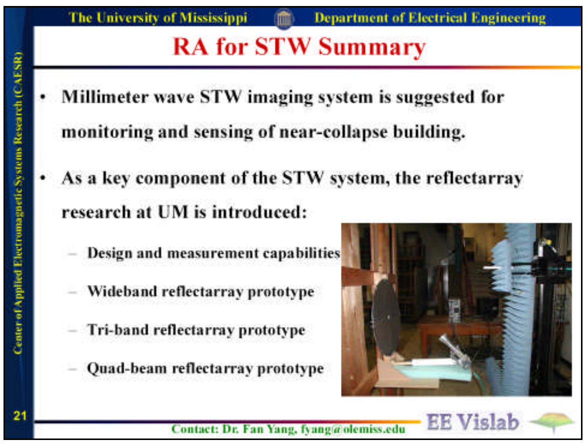
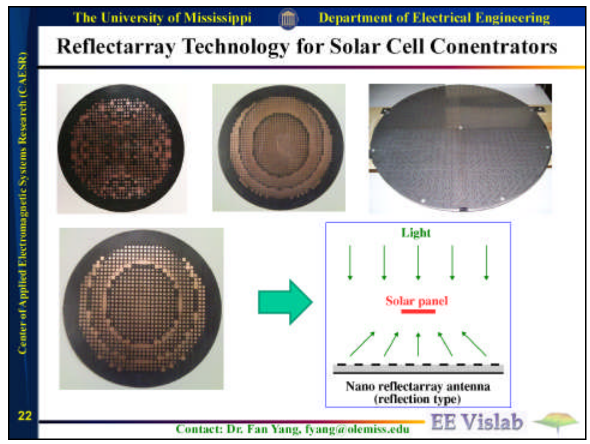
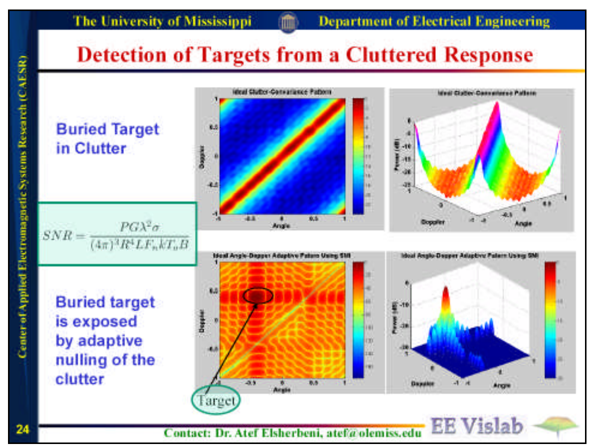


	Peak Gain (dB)	Center Frequency (f_c)	-1 dB Bandwidth (%)	η_a @ f_c (%)
Ka	38.7	31.8	6.3	20.6
X	29.1	8.4	2.0	26.5
C	28.4	7.1	1.8	38.8









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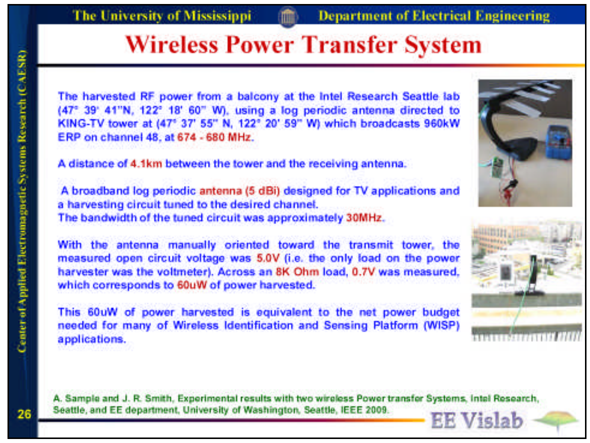
Wireless Power Transfer System
Apparatus for ambient RF harvesting experiment. The power harvester (the PC board in the lower left) is fed by the log period antenna. The harvester output is connected to an 8K Ohm resistive load and a volt meter.
Operating a temperature and humidity meter (including LCD display) using only ambient RF power.
A. Sample and J. R. Smith, Experimental results with two wireless Power taransfer Systems, Intel Research, Seattle, and EE department, University of Washington, Seattle, IEEE 2009.
25
EE Vislab



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Center of Applied Electromagnetic Systems Research (CAESR)
Wireless Power Transfer System
The harvested RF power from a balcony at the Intel Research Seattle lab (47° 39' 41"N, 122° 18' 60" W), using a log periodic antenna directed to KING-TV tower at (47° 37' 55" N, 122° 20' 59" W) which broadcasts 960kW ERP on channel 48, at 674 - 680 MHz.
A distance of 4.1km between the tower and the receiving antenna.
A broadband log periodic antenna (5 dBi) designed for TV applications and a harvesting circuit tuned to the desired channel.
The bandwidth of the tuned circuit was approximately 30MHz.
With the antenna manually oriented toward the transmit tower, the measured open circuit voltage was 5.0V (i.e. the only load on the power harvester was the voltmeter). Across an 8K Ohm load, 0.7V was measured, which corresponds to 60uW of power harvested.
This 60uW of power harvested is equivalent to the net power budget needed for many of Wireless Identification and Sensing Platform (WISP) applications.
A. Sample and J. R. Smith, Experimental results with two wireless Power transfer Systems, Intel Research, Seattle, and EE department, University of Washington, Seattle, IEEE 2009.
26
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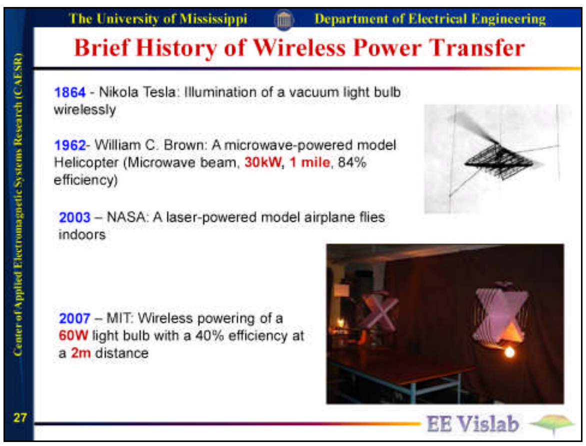

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Brief History of Wireless Power Transfer
1864 - Nikola Tesla: Illumination of a vacuum light bulb wirelessly
1962- William C. Brown: A microwave-powered model Helicopter (Microwave beam, 30kW, 1 mile, 84% efficiency)
2003 – NASA: A laser-powered model airplane flies indoors
2007 – MIT: Wireless powering of a 60W light bulb with a 40% efficiency at a 2m distance
27
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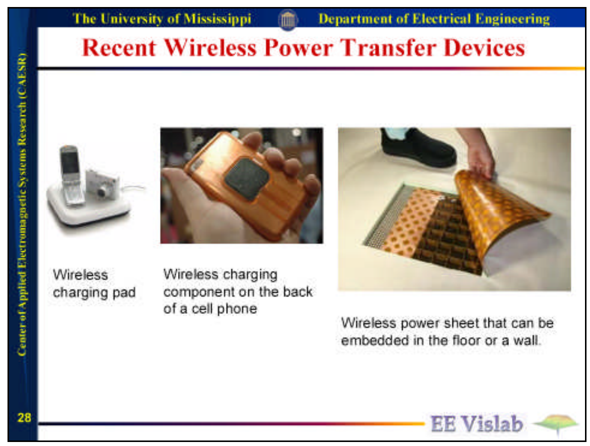

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Recent Wireless Power Transfer Devices
Wireless charging pad
Wireless charging component on the back of a cell phone
Wireless power sheet that can be embedded in the floor or a wall.
28
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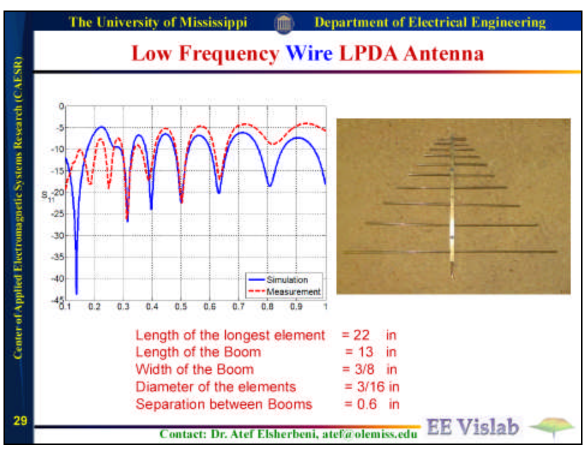

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Center of Applied Electromagnetic Systems Research (CAESR)
Low Frequency Wire LPDA Antenna
Simulation
Measurement
Length of the longest element = 22 in
Length of the Boom = 13 in
Width of the Boom = 3/8 in
Diameter of the elements = 3/16 in
Separation between Booms = 0.6 in
29
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
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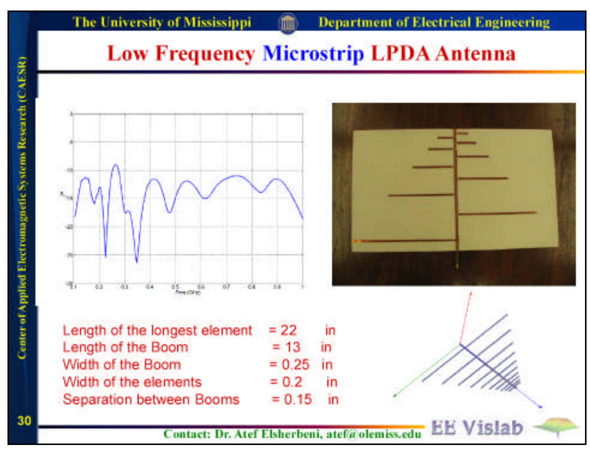

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Low Frequency Microstrip LPDA Antenna
Length of the longest element = 22 in
Length of the Boom = 13 in
Width of the Boom = 0.25 in
Width of the elements = 0.2 in
Separation between Booms = 0.15 in
30
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
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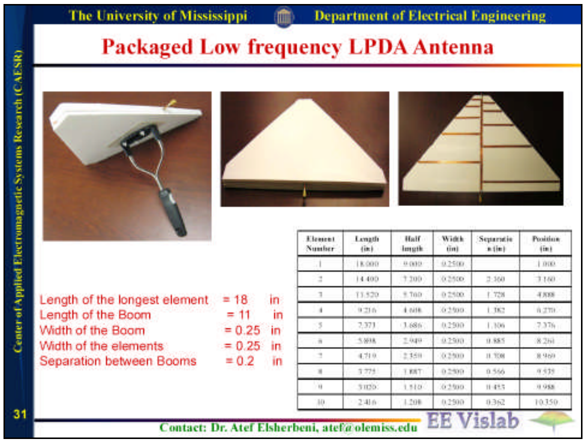

The University of Mississippi
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Center of Applied Electromagnetic Systems Research (CAESR)
Packaged Low frequency LPDA Antenna
Length of the longest element = 18 in
Length of the Boom = 11 in
Width of the Boom = 0.25 in
Width of the elements = 0.25 in
Separation between Booms = 0.2 in
Element Number | Length (in) | Half length | Width (in) | Separation (in) | Position (in)
1 | 18.000 | 9.000 | 0.2500 | | 1.000
2 | 14.400 | 7.200 | 0.2500 | 2.160 | 3.160
3 | 11.520 | 5.760 | 0.2500 | 1.728 | 4.888
4 | 9.216 | 4.608 | 0.2500 | 1.382 | 6.270
5 | 7.373 | 3.686 | 0.2500 | 1.106 | 7.376
6 | 5.898 | 2.949 | 0.2500 | 0.885 | 8.260
7 | 4.719 | 2.359 | 0.2500 | 0.708 | 8.969
8 | 3.775 | 1.887 | 0.2500 | 0.566 | 9.535
9 | 3.020 | 1.510 | 0.2500 | 0.453 | 9.988
10 | 2.416 | 1.208 | 0.2500 | 0.362 | 10.350
31
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
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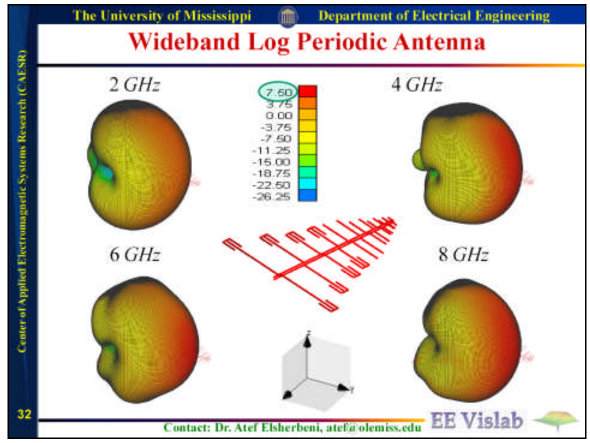

The University of Mississippi
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Center of Applied Electromagnetic Systems Research (CAESR)
Wideband Log Periodic Antenna
2 GHz
4 GHz
6 GHz
8 GHz
32
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
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The University of Mississippi
Department of Electrical Engineering
Center of Applied Electromagnetic Systems Research (CAESR)
Analysis, Design and Fabrication of Wideband Slot and Printed Antennas and Antenna Arrays
33
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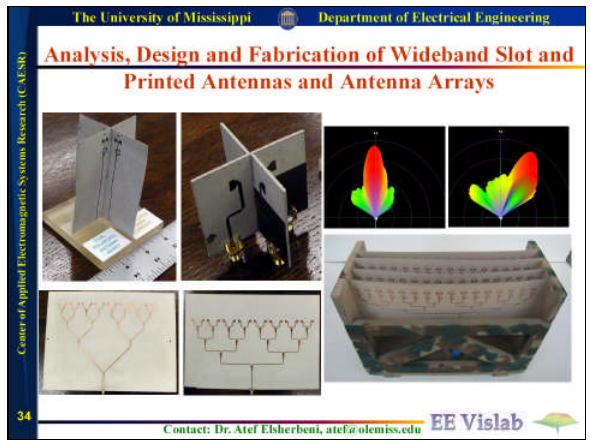
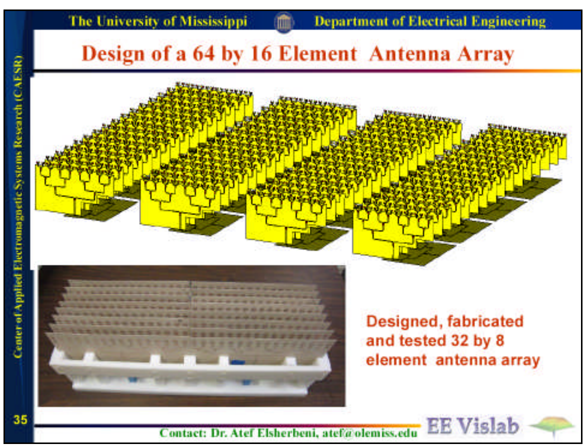


The University of Mississippi
Department of Electrical Engineering
Center of Applied Electromagnetic Systems Research (CAESR)
Analysis, Design and Fabrication of Wideband Slot and Printed Antennas and Antenna Arrays
34
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
EE Vislab



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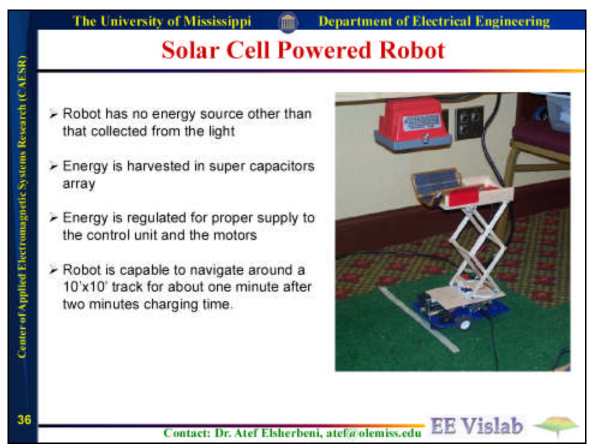
Design of a 64 by 16 Element Antenna Array
Designed, fabricated and tested 32 by 8 element antenna array
35
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
EE Vislab



The University of Mississippi
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Center of Applied Electromagnetic Systems Research (CAESR)
Solar Cell Powered Robot
Robot has no energy source other than that collected from the light
Energy is harvested in super capacitors array
Energy is regulated for proper supply to the control unit and the motors
Robot is capable to navigate around a 10'x10' track for about one minute after two minutes charging time.
36
Contact: Dr. Atef Elsherbeni, atef@olemiss.edu
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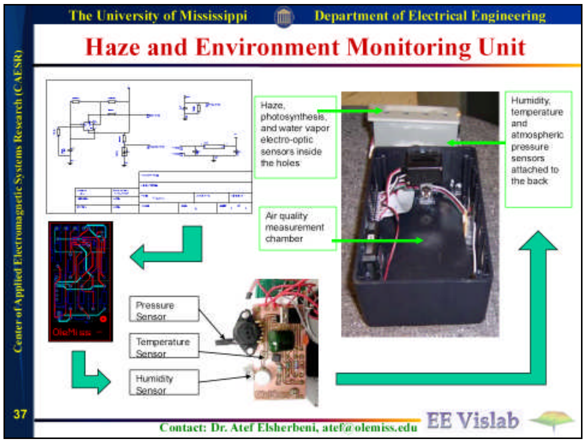
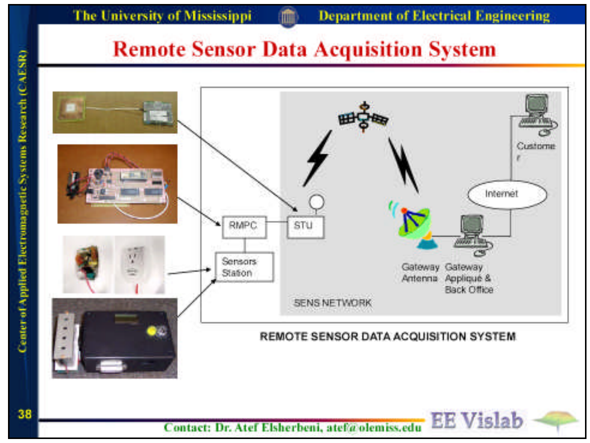
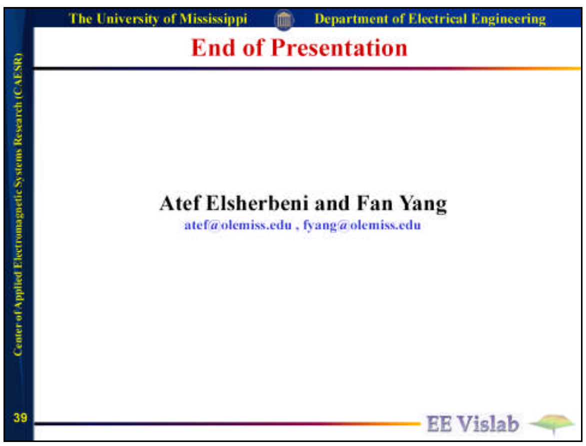






• • •

Chung Song

Dr. Chung R. Song obtained his B.S. degree from Yonsei University, Seoul, Korea in 1984, and M.S. degree from The University of Texas at Austin in 1986 for his research on Soil Dynamics. He obtained a Ph.D. degree from Louisiana State University for research on computational analysis of large strain problems. He obtained PE qualification in 1993 in Korea, and earned an International PE in 2002. He has published more than 70 articles, three book chapters, and two books. His industry career includes more than 10 years of consulting experience in the area of geotechnical/geo-structural design, analysis, and instrumentation.

Dr. Song's specialty areas are the evaluation of physical and mechanical behavior of geotechnical structures and combination of noble theories and real field problems such as bridging sophisticated analytical models and field monitoring results, nano-particulate-continuum mechanics, implementation of acoustic techniques in subsoil exploration, the behavior evaluation of geotechnical structures, soft soil improvement, constitutive relations of geo-materials, simulation of saturated/unsaturated soils using coupled theory of mixtures, numerical modeling, calibration chamber testing, soil dynamics, soil-structure interaction, in situ and laboratory testing, and pavement-related geotechnical engineering.

Implementation of a Ubiquitous System to Monitor Near-Collapse Buildings

The proper monitoring and sensing of near-collapse buildings are imperative for effective rescue work and safety of the rescue crew members. However, the monitoring and sensing tasks are performed in one of the most critical situations; failure may be imminent, flame and high heat source may exist, and high VOC gases may be present, but the monitoring and sensing should be done quickly and reliably. The data should also be analyzed real time basis so that it can be used quick decision making.

Considering these critical requirements, the monitoring system should satisfy the following requirements;

1) Sensors should have high heat/stress resistance.
2) Sensors should be tele-measurable, possibly by wireless.
3) Most sensors should be pre-installed.
4) …but global monitoring systems should be able to incorporate newly installed sensing system such as Laser Vibrometer data, first responders digital photos and sensors, etc.
5) A decision-making system should be already set up, but it should be capable of taking human inputs and sensor inputs simultaneously, such as AI (Artificial Intelligence).

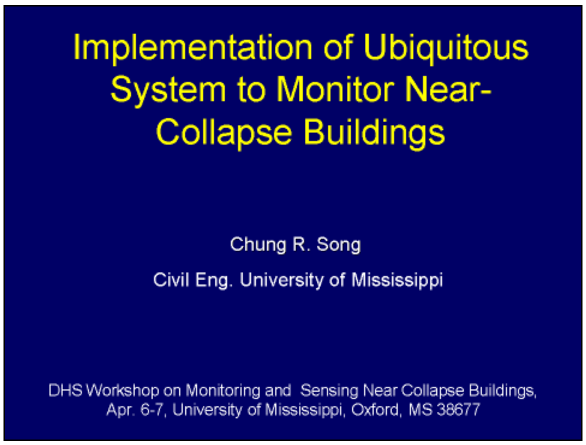
Hardware requirements are resolved without too much difficulty. However, the interface between the monitored results and decision making system is not easy to achieve, but they are attainable considering technology development in other areas. NASA developed Integrated System Health Management (ISHM) that essentially takes sensor readings, checks for errors, analyzes the data, and provides the crude information to engineers to monitor and control the space ship launch. A similar system for broader application is called "Ubiquitous System" or "Ambient Computing System" and has been developed and used.

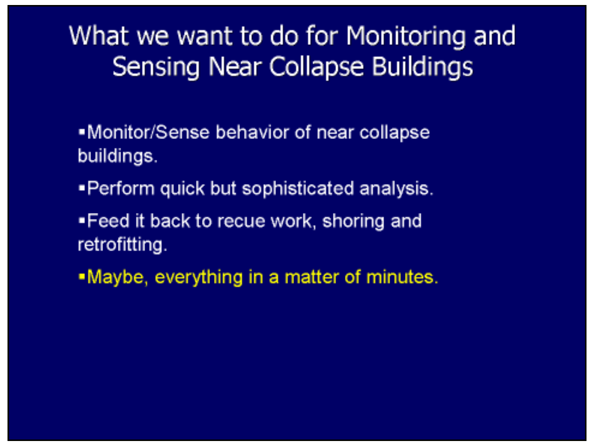
Using an example scenario in Wikipedia (http://en.wikipedia.org/wiki/Ambient_intelligence), an application scenario of "Ubiquitous System" for near-collapse buildings can be recomposed as follows;

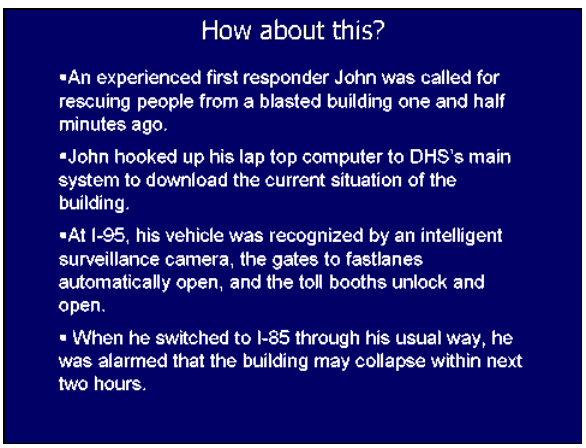
An experienced first responder John was called for rescuing people from a blasted building one and half minutes ago. John hooked up his lap top computer to the DHS's main system to download the current situation of the building. At I-95, his vehicle was recognized by an intelligent surveillance camera, the gates to fastlanes are automatically open, and the toll booths unlock and open. When he switched to I-85 to through his usual way, he was alarmed that the building may collapse within next two hours, and the navigation map indicates that a bridge ahead of his route is overloaded. A lap top computer in his vehicle collects additional sensor signals using RFID technology along while driving and send them to the Ubiquitous System simultaneously, the Ubiquitous System outputs stresses and other mechanical information to his lap top computer and performs structural analysis of the building and update the condition of the building. When John arrives at the site, his vehicle turns on 3-D laser vibrometer, starts to collect multiple deformation data, and updates him the current condition of the building.

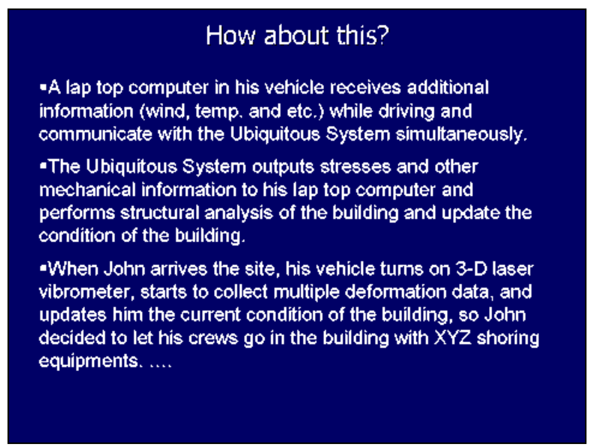
The critical technologies needed for this ubiquitous/ambient intelligence are GPS/Digital Map/Wireless Communication/Wired and Wireless Sensors. With the advent of modern MEMs (Micro-Electro-Mechanical System), most needed technologies are already developed. Therefore, implementation of "Ubiquitous System" shall provide a complete solution for monitoring near-collapse buildings.

Presentation Slides









Challenges

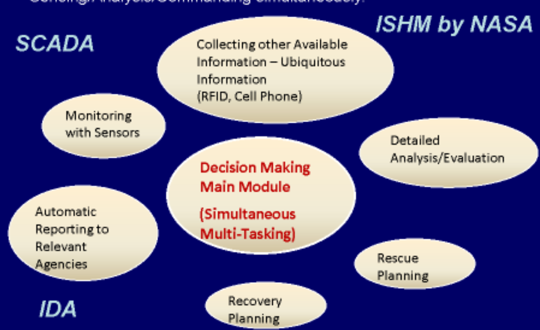
- Sensors must be quickly deployable.
- Must be able to work with existing sensors (wired/wireless).
- Must be wireless (new sensors).
- Must be able to collect signals from ambient sensors. (e.g. RFID, Cell Phones,…)
- Expandability to new sensors and equipments.
- Must be synchronized with existing analysis/decision making system (Plug & Play).
- Maybe, everything in a matter of minutes.

The Good News is…

Sensors must be quickly deployable.	Available
Must be able to work with existing sensors.	Possible with sensor networking tech.
Must be wireless (new sensors).	No problem.
Must be able to collect signals from ambient sensors.	Technology is there. Need to setup a system.
Expandability to new sensors and equipments.	Possible with sensor networking tech.
Must be synchronized with existing analysis/decision making system (Plug in & Play).	Possible with sensor networking tech. and advanced analysis system.
Maybe, everything in a matter of minutes.	Yes, with an Ubiquitous System.

Ubiquitous System

It's in everywhere!
Sensing/Analysis/Commanding simultaneously.



Sensors I: Common sensors

Stress	Electric Resistivity
Deformation	Vibrating Wire
Tilting	Servo Accel. EL Inclinometer
Temperature	RTD
Vibration	Piezoelectric, Coil Type,…

Sensors II: Wireless Sensors

Can be glued, bolted, welded…
Wireless !
Networked !!
Can be self powered !!!
Inexpensive

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Sensors II: Wireless Sensors Currently developed/used for

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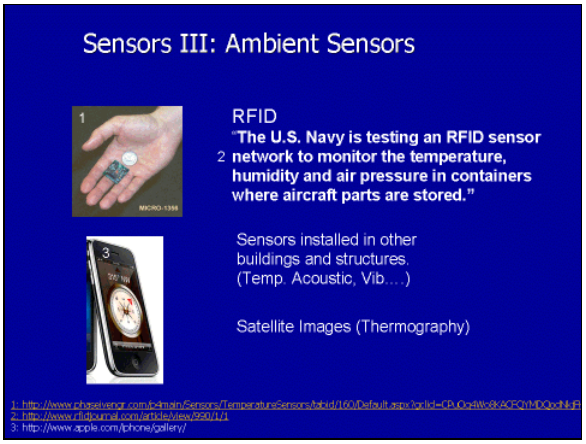
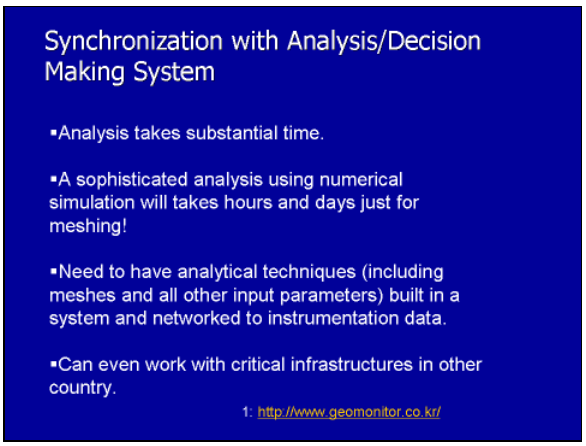


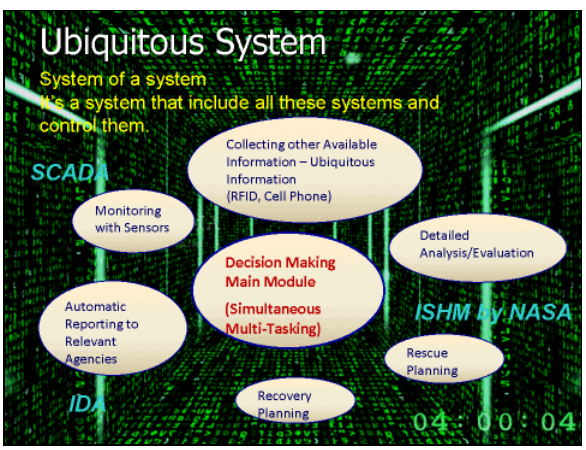
Sensors III: Ambient Sensors
1
RFID
"The U.S. Navy is testing an RFID sensor network to monitor the temperature, humidity and air pressure in containers where aircraft parts are stored."
2
3
Sensors installed in other buildings and structures. (Temp. Acoustic, Vib.…)
Satellite Images (Thermography)
2: http://www.rfidjournal.com/article/view/990/1/1
3: http://www.apple.com/iphone/gallery/

Expandability to additional sensors and equipments
Laser Vibrometer (1)
Digitally expandable networking system is commercially available.
A custom made system can be designed (e.g. ISHM by NASA).
1: Graphtec Inc.

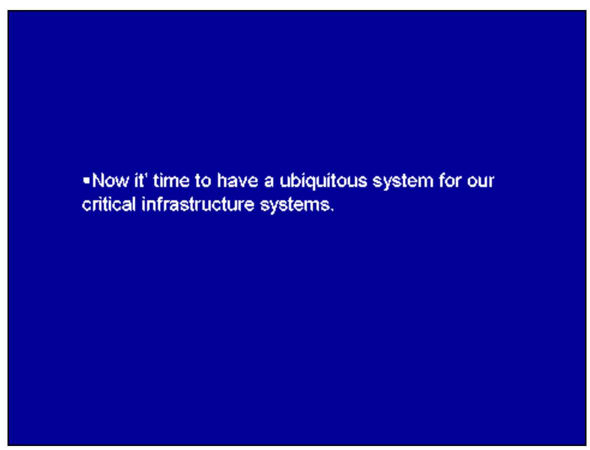


Synchronization with Analysis/Decision Making System
▪Analysis takes substantial time.
▪A sophisticated analysis using numerical simulation will takes hours and days just for meshing!
▪Need to have analytical techniques (including meshes and all other input parameters) built in a system and networked to instrumentation data.
▪Can even work with critical infrastructures in other country.
1: http://www.geomonitor.co.kr/

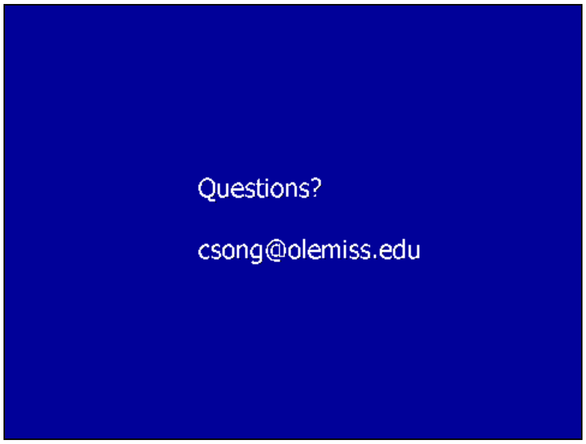
Are we there yet?
Total 965 sensors



Ubiquitous System
System of a system
It's a system that include all these systems and control them.
SCADA
Collecting other Available Information – Ubiquitous Information (RFID, Cell Phone)
Monitoring with Sensors
Detailed Analysis/Evaluation
Decision Making Main Module (Simultaneous Multi-Tasking)
Automatic Reporting to Relevant Agencies
ISHM by NASA
Rescue Planning
Recovery Planning
IDA
04 : 00 : 04



▪Now it' time to have a ubiquitous system for our critical infrastructure systems.


Questions?
csong@olemiss.edu

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SESSION 6

THE FUTURE OF SENSING

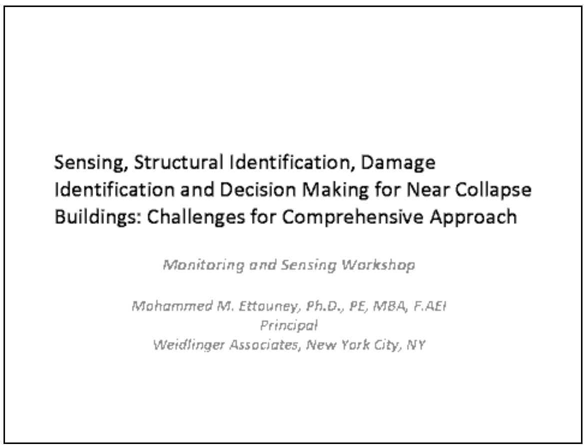
Mohammed Ettouney

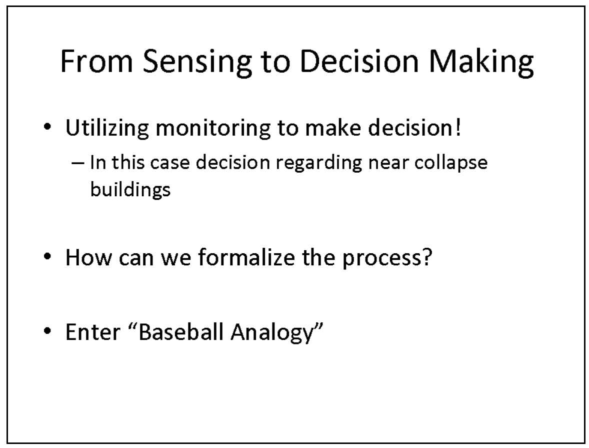
A biography of Dr. Ettouney can be found on page 10.

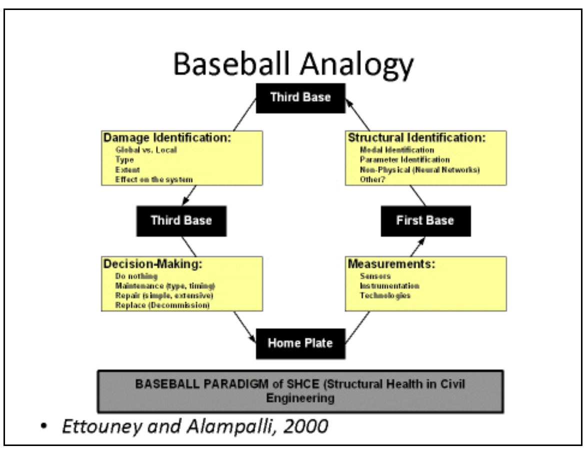
Sensing, Structural Identification, Damage Identification, and Decision Making for Near-Collapse Buildings: Challenges for a Comprehensive Approach

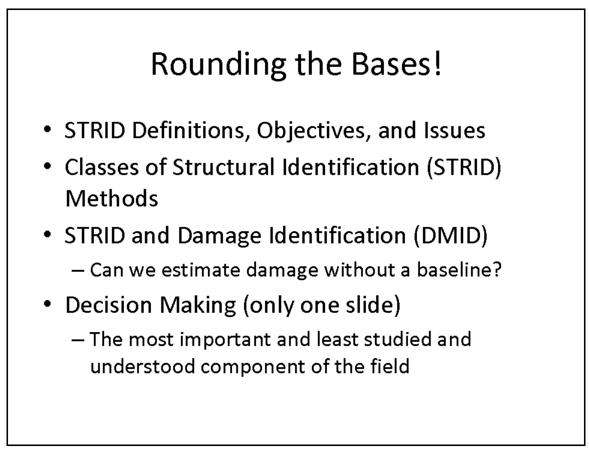
This presentation focused on the ways to use structural identification to detect damage in near-collapse buildings. The presentation outlined the definition, objectives, and issues associated with structural identification (STRID). The many methods of structural identification, from modal identification to energy modeling methods, were discussed. Finally, a STRID decision-making tool box was presented.

Presentation Slides









What is Structural Identification?

- Use a set of measurements from a sensing experiment to
  - Establish some dynamic properties of structure, such as
    - modal shapes, damping and frequencies (Modal identification)
    - Dispersion Curves
    - Energy flow models
  - Improve analytical modeling (large finite element model)
    - Parameter identification
    - Neural Networks

Objectives of Structural Identification

- Structural (a.k.a. System) identification utilizes measurements to
  - Validate design / analytical techniques (mostly new structures)
  - Condition Assessment of existing Structures
    - Condition of near collapse buildings
  - Damage Identification
    - Most of Structural Identification Methods Purport that it can identify damage
    - Is that true?

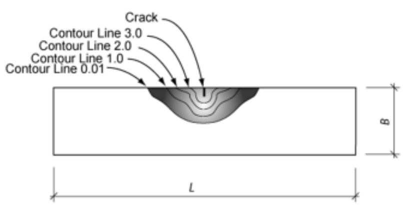
Structural Identification Methods

- Modal Identification
- Parameter Identification
- Scale Independent Methods
- Dispersion Curves (Methods)
- Energy Modeling Methods, e.g., SEA (Statistical Energy Analysis)

Isues with Structural Identification

- Error Scaling
- Dynamic Scaling
- Spatial Scaling
- Geometric Modeling

Structural Identification: Local Damage



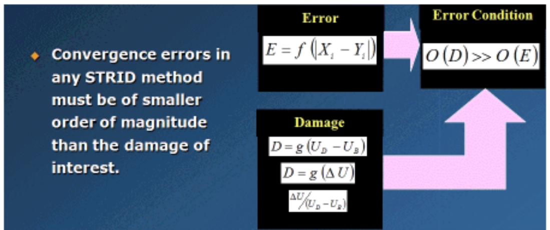
Dynamic Pressure Bulb

- Can you build a structural model that can detect the performance of this damage?
- How many modes are needed?
- How small is the element should be?
- Now generalize this to a complex system, say a building…

Damage and Structural Identification

- Can you build a structural model that can detect the performance of this damage?
- How much tolerance should be allowed in the numerical procedures? (Error)
- How many modes are needed? (Dynamic)
- How small is the element should be? (Spatial)
- How detailed the model should be? (Geometric)
- Now generalize this to a complex system, say a bridge…

Error Scale

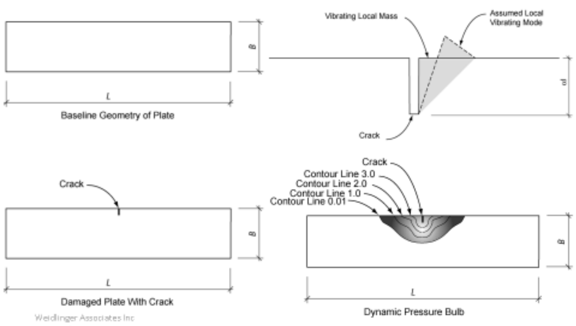


Admittedly, this is a strict limitation. However, if it is not accommodated, then the StrId method of interest is not adequate in identifying the damage of interest. The error scale is applicable to all StrId methods when used for damage identification.

Dynamic Scale – 1

- STRID Vibration methods that purports to identify damage must be consistent with the dynamic properties of the damages they are trying to identify
- Any change of properties (damage) will have some dynamic foot prints
  - Frequency range
  - Mode shapes and amplitudes
- The STRID method must be robust and accurate in the damage's frequency range

Dynamic Scale – 2



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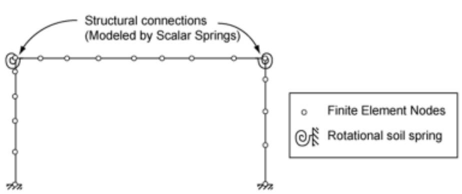
Spatial Scale - 1

- Spatial Scale refers to the resolution of the finite element (or any other numerical technique) as compared with the expected damage size
- If there is a mismatch in element and damage size, the damage effects will be averaged (smeared) and the accuracy of damage detection would be reduced

Spatial Scale - 2



- Modeling structural connection/joints by set of scalar springs in order to detect 'damage' within the connection can lead to in-accurate results
  - Especially if the damage is not wide-spread

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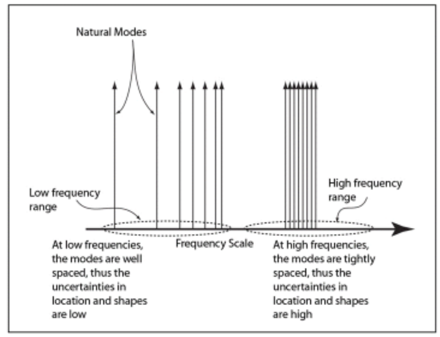
Geometric Modeling - 1

- Geometric modeling accuracy refers to the adequacy of simulating the behavior of the structure near expected damage areas
- If such a simple rule is not followed, the result would be averaging of damage effects
  - Such an averaging might result in a loss of accuracy, or
  - Detecting a very different 'damage' and actual one.

Geometric Modeling - 2

- It is popular to model columns / beams by a 'beam element'
  - Basic assumption is rigid cross section assumption
  - It is not clear how such a model can detect a damage that might induce an out-of plane deformation!!!
- Yet, many validation studies use such a modeling technique!

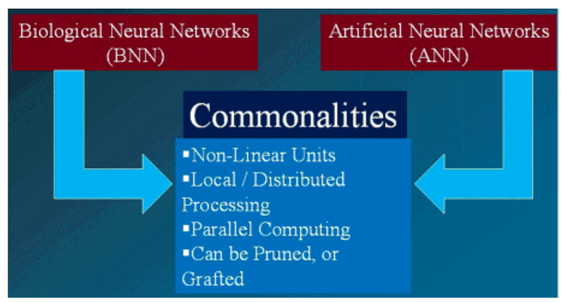
The Fallacy of Modal ID in Civil Infrastructures



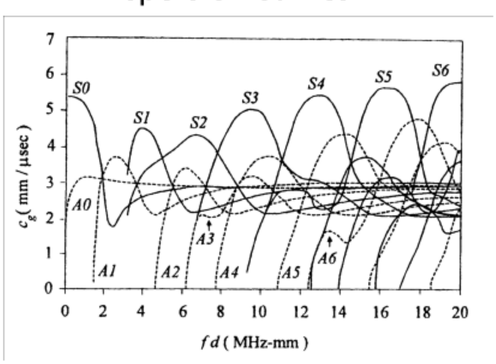
Neural Networks

- Popular Structural ID Method
- Used when formal, e.g., Finite Elements method can't be used

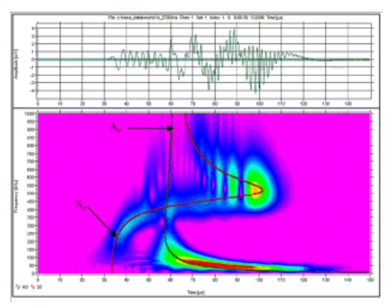
ANN vs BNN



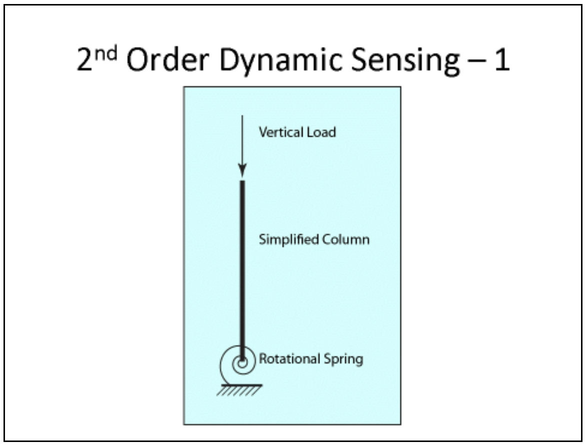
Dispersion Curves – 1



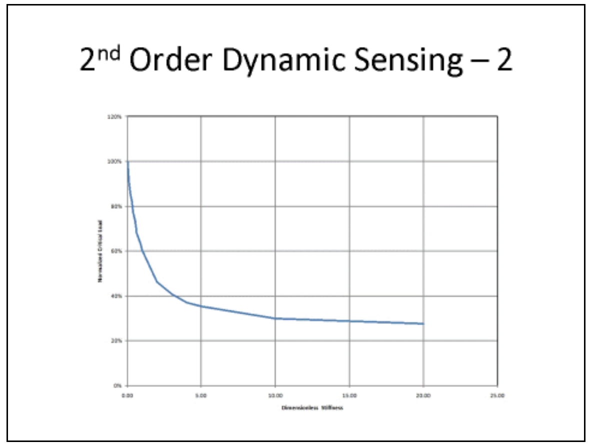
Dispersion Curves – 2



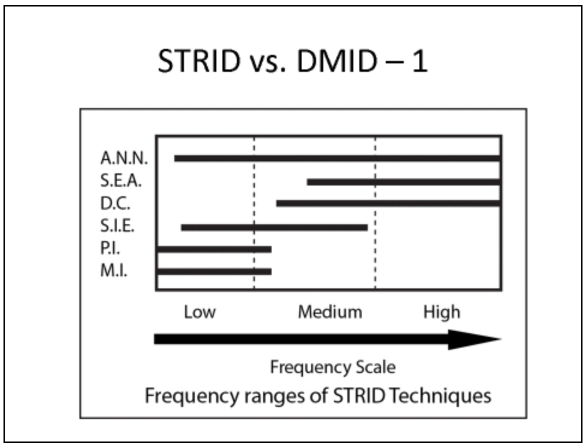
- Acoustic Emission
- Wavelet Analysis
- Dispersion curves
- Direct damage detection



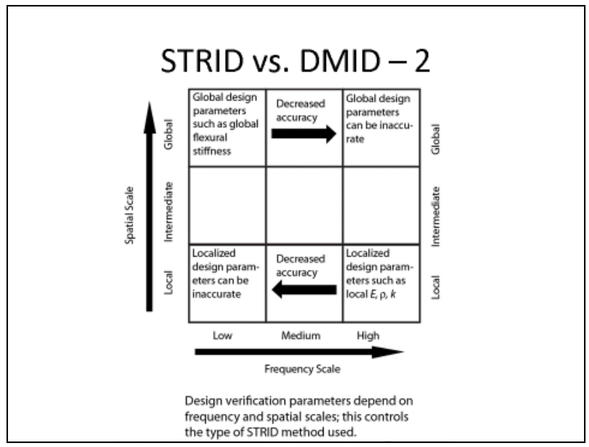
2nd Order Dynamic Sensing – 1
Vertical Load
Simplified Column
Rotational Spring



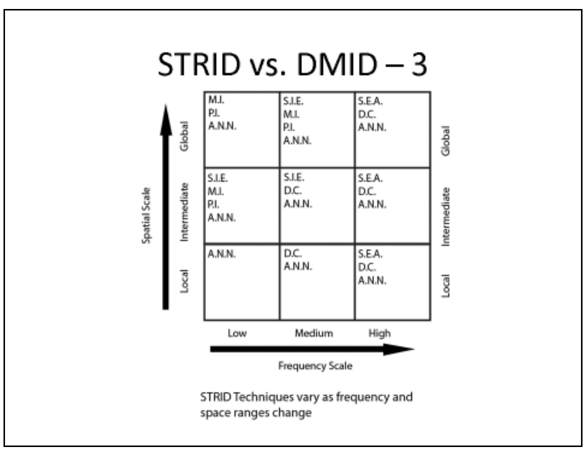
2nd Order Dynamic Sensing – 2
120%
100%
80%
60%
40%
20%
0%
0.00
5.00
10.00
15.00
20.00
25.00
Dimensionless Stiffness



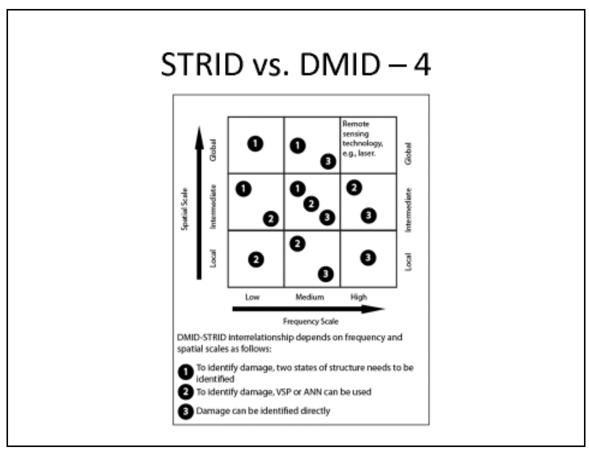
STRID vs. DMID – 1
A.N.N.
S.E.A.
D.C.
S.I.E.
P.I.
M.I.
Low
Medium
High
Frequency Scale
Frequency ranges of STRID Techniques



STRID vs. DMID – 2
Global design parameters such as global flexural stiffness
Decreased accuracy
Global design parameters can be inaccurate
Localized design parameters can be inaccurate
Decreased accuracy
Localized design parameters such as local E, ρ, k
Spatial Scale
Global
Intermediate
Local
Low
Medium
High
Frequency Scale
Design verification parameters depend on frequency and spatial scales; this controls the type of STRID method used.

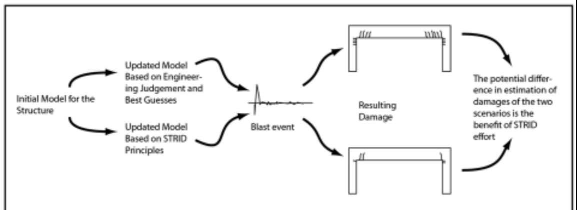


STRID vs. DMID – 3
M.I.
P.I.
A.N.N.
S.I.E.
M.I.
P.I.
A.N.N.
S.E.A.
D.C.
A.N.N.
S.I.E.
M.I.
P.I.
A.N.N.
S.I.E.
D.C.
A.N.N.
S.E.A.
D.C.
A.N.N.
A.N.N.
D.C.
A.N.N.
S.E.A.
D.C.
A.N.N.
Spatial Scale
Global
Intermediate
Local
Low
Medium
High
Frequency Scale
STRID Techniques vary as frequency and space ranges change



STRID vs. DMID – 4
Remote sensing technology, e.g., laser.
Spatial Scale
Global
Intermediate
Local
Low
Medium
High
Frequency Scale
DMID-STRID interrelationship depends on frequency and spatial scales as follows:
1 To identify damage, two states of structure needs to be identified
2 To identify damage, VSP or ANN can be used
3 Damage can be identified directly

Cost Benefit of STRID



Pre-Event STRID Strategy

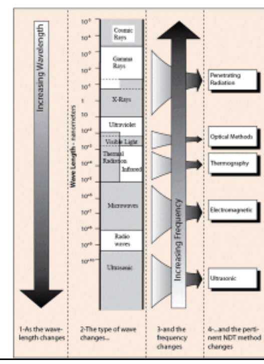
Damage Identification

- Identify
  - Did damage occur?
  - Where?
  - How much?
  - Implications?
- Types of damage (for near collapse buildings)
  - Instability (Global)
  - Instability (Local)
  - Component (Beams, Columns, etc.) failures
  - Large Deformation (impact, delamination, etc...)
  - Non-Structural failures

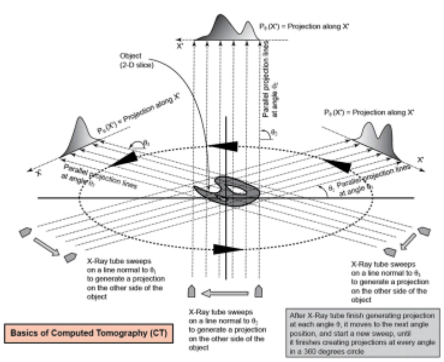
Can we detect damage directly?

- Many methods are available
  - Radiation (CATScan)
  - Ultrasonic (Impact Echo)

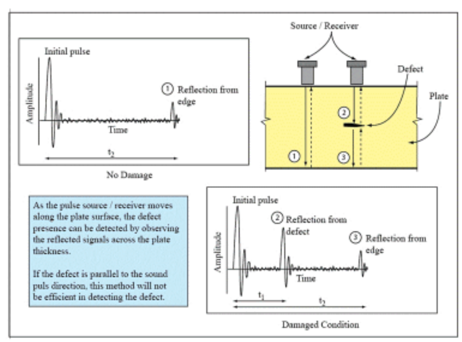
Wave Length Spectrum

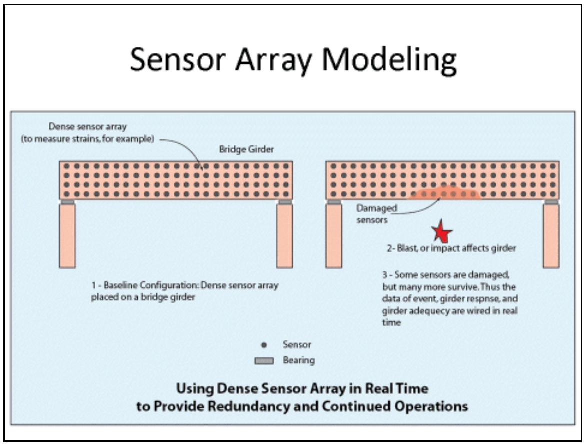


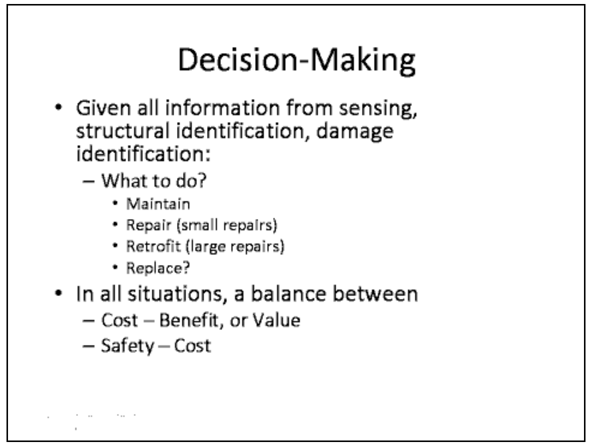
CATScan

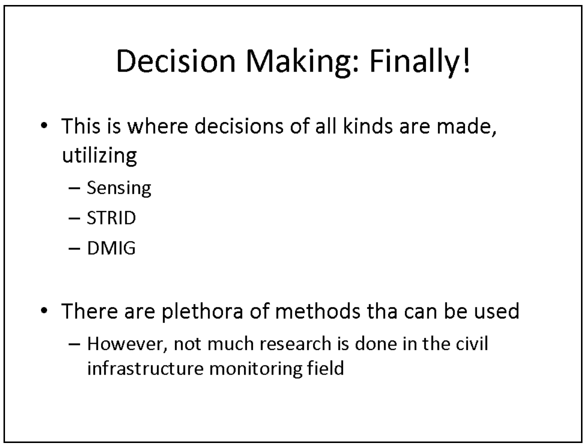


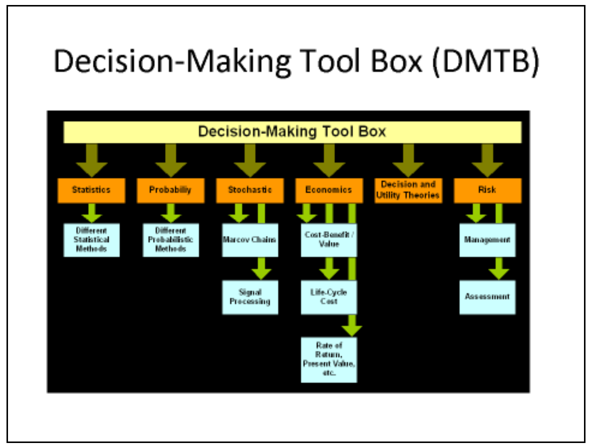
Impact Echo











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Greg Easson

Dr. Greg Easson is the Executive Director of the Mississippi Mineral Resources Institute (MMRI) at The University of Mississippi. Prior to becoming MMRI Executive Director, Easson was a Professor in the Department of Geology and Geological Engineering where he taught GIS and Remote Sensing classes for 14 years. Easson is also the Executive Director of the Enterprise for Innovative Geospatial Solutions a university-wide program to coordinate research activities in Geospatial Information Science and Technology (GIS&T) and the Director of The University of Mississippi Geoinformatics Center, an interdisciplinary research and educational initiative designed to increase the use and awareness of GIS&T.

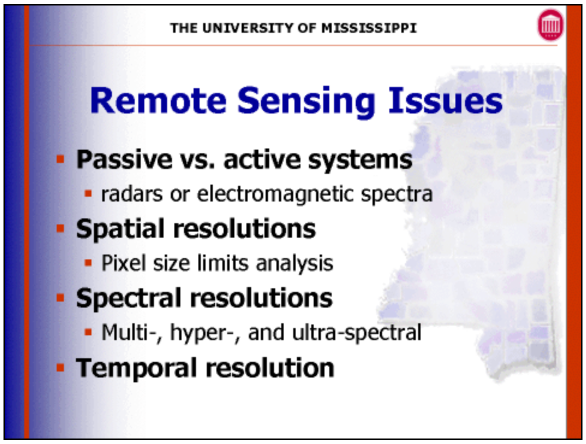
Easson received his Ph.D. from the University of Missouri – Rolla in Geological Engineering in 1995. He received his master's degree in Geology also from the University of Missouri – Rolla in 1984 and a bachelor's degree from Southwest Missouri State University in 1981.

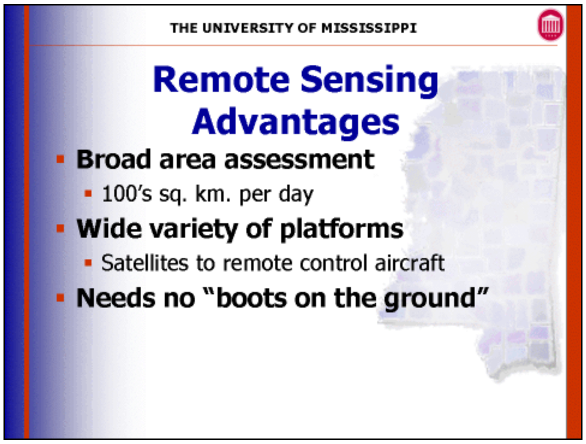
Easson has more than 25 years of experience in the application of GIS&T in Federal and State government, with employment at the Missouri Department of Natural Resources and the U.S. Geological Survey.

Rapid Building Damage Assessment from Remotely Sensed Imagery

In the aftermath of major disasters, such as Hurricane Katrina and the World Trade Center collapse, State and local agencies are charged with assessing damage to structures to determine risk and assess needs for response. This assessment is needed to begin to determine the magnitude of the damage and the amount of materials and supplies that will be needed to effectively respond. The acquisition of multispectral imagery immediately after a disaster is routine, even in international situations when the International Charter is activated. After Hurricane Katrina struck the Mississippi Gulf Coast, the National Oceanic and Atmospheric Administration (NOAA) and other agencies collected multispectral imagery at an average spatial resolution of one-meter. This 4-band imagery was acquired from airborne sensors. In addition to the Federal agencies acquiring imagery, many commercial companies were also acquiring multispectral imagery. The majority of imagery acquired for this and most disaster is acquired at nadir; looking directly down on the target of interest. This limits the ability of imagery analyst to assess the structural reliability of buildings. There are however, many ways in which remotely sensed imagery can be used to assess structures in the aftermath of a major hurricane. Researchers at the University of Mississippi, University of South Carolina, and NASA have developed a decision support system that guides users through the selection of remotely sensed imagery for disaster response, including building assessment. This presentation shows how the system can be used to select imagery for assessing building damage and the limitations of imagery for assessing building condition following major disasters, including storms and terrorist attacks.

Presentation Slides





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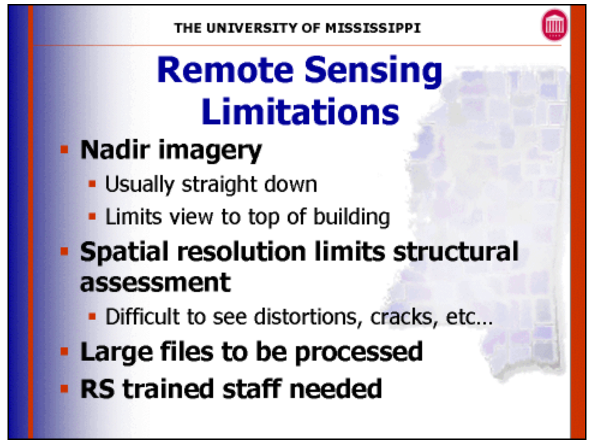
Remote Sensing Advantages
Broad area assessment
100's sq. km. per day
Wide variety of platforms
Satellites to remote control aircraft
Needs no "boots on the ground"



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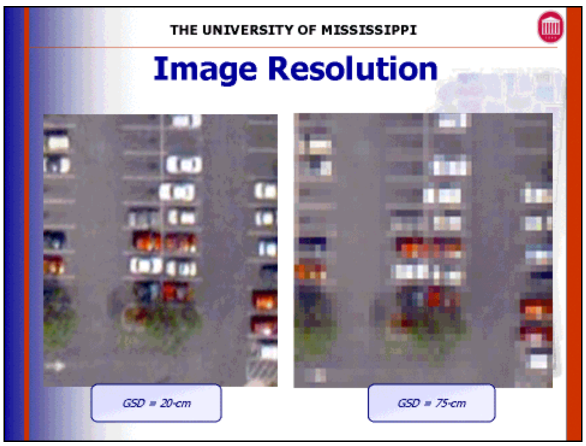
Remote Sensing Limitations
Nadir imagery
Usually straight down
Limits view to top of building
Spatial resolution limits structural assessment
Difficult to see distortions, cracks, etc…
Large files to be processed
RS trained staff needed



THE UNIVERSITY OF MISSISSIPPI
Image Resolution
GSD = 20-cm
GSD = 75-cm

THE UNIVERSITY OF MISSISSIPPI
Image Resolution
GSD = 15cm
GSD = 30cm
GSD = 45cm
GSD = 60cm
Original imagery is degraded using simple pixel averaging to simulate imagery acquired at three lower spatial resolutions

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Image Resolution
GSD = 1.2 ft
GSD = 2.4 ft
GSD = 3.6 ft
GSD = 4.8 ft

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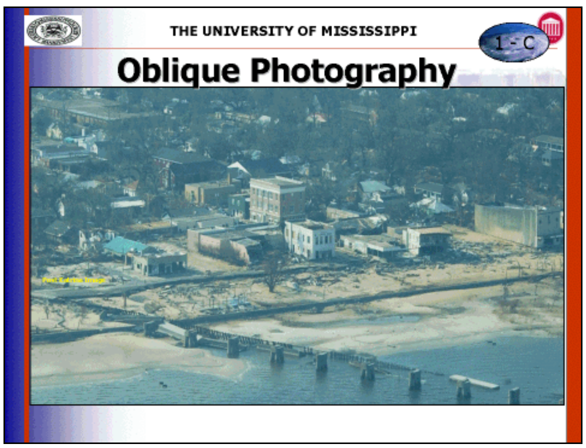
Image Resolution

THE UNIVERSITY OF MISSISSIPPI
Oblique Imagery

THE UNIVERSITY OF MISSISSIPPI
Oblique Imagery



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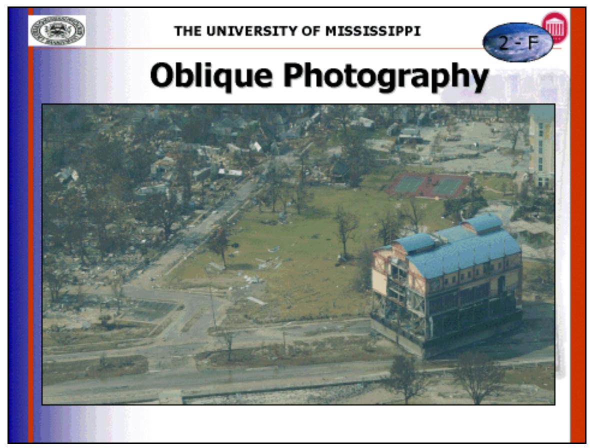
1 - C
Oblique Photography



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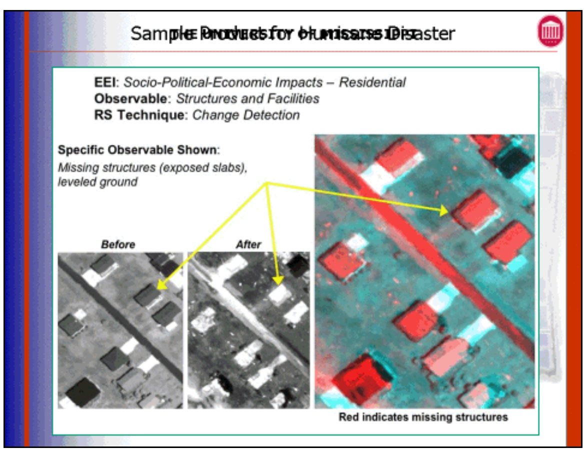
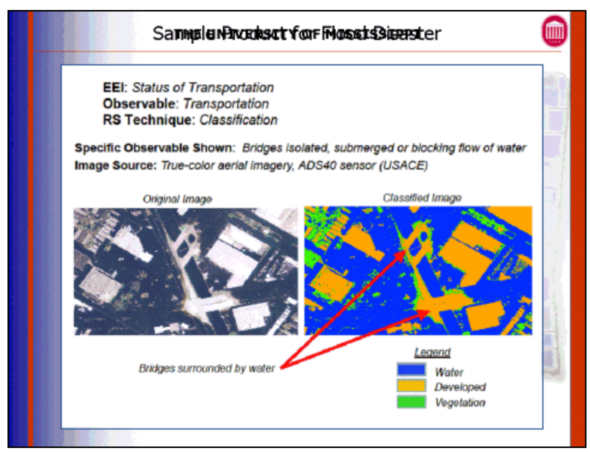
2 - F
Oblique Photography



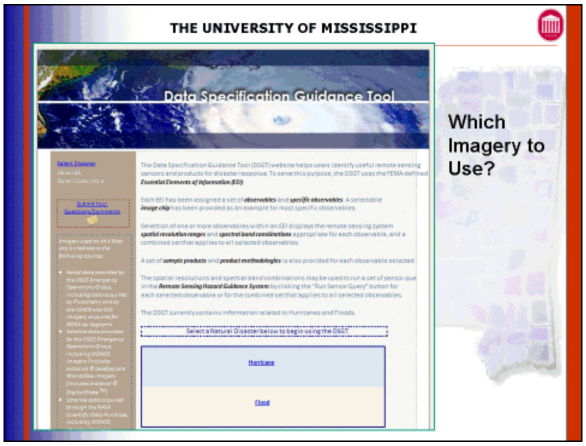
EEI: Socio-Political-Economic Impacts – Residential
Observable: Structures and Facilities
RS Technique: Change Detection
Specific Observable Shown:
Missing structures (exposed slabs), leveled ground
Before
After
Red indicates missing structures



EEI: Status of Transportation
Observable: Transportation
RS Technique: Classification
Specific Observable Shown: Bridges isolated, submerged or blocking flow of water
Image Source: True-color aerial imagery, ADS40 sensor (USACE)
Original Image
Classified Image
Bridges surrounded by water
Legend
Water
Developed
Vegetation

SESSION 6

THE FUTURE OF SENSING



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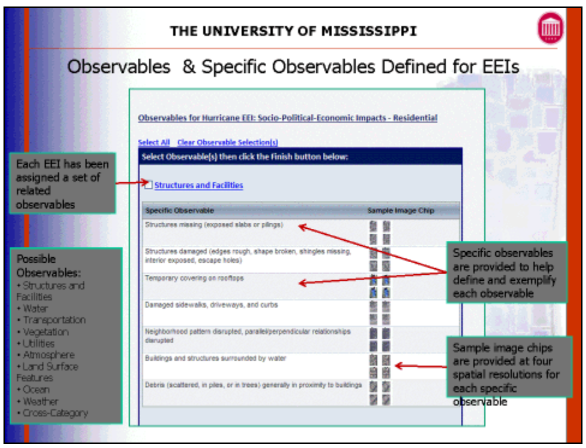
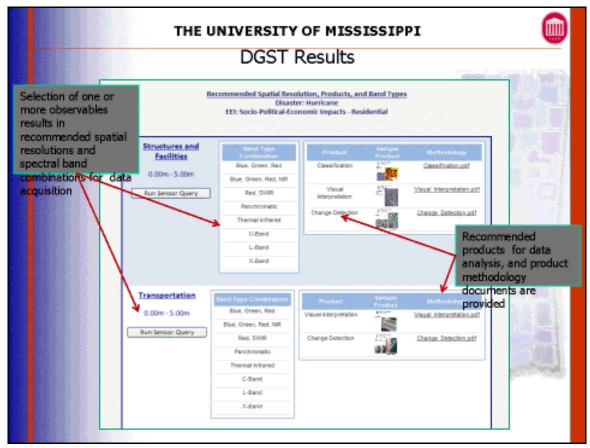
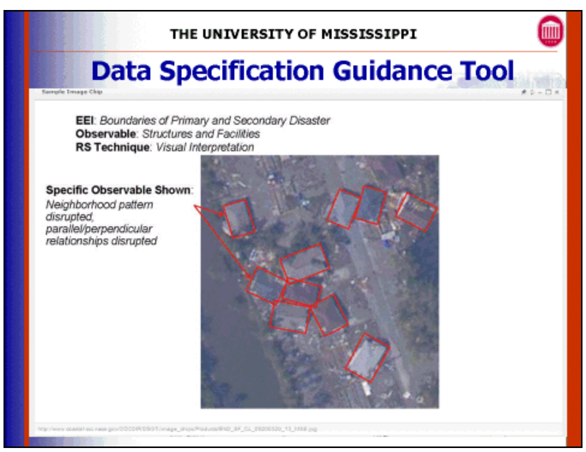
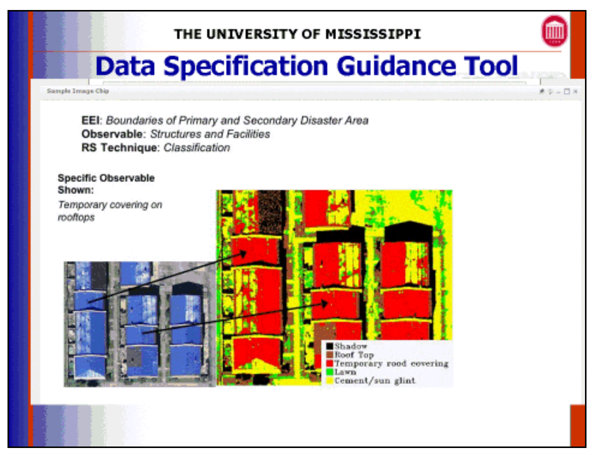
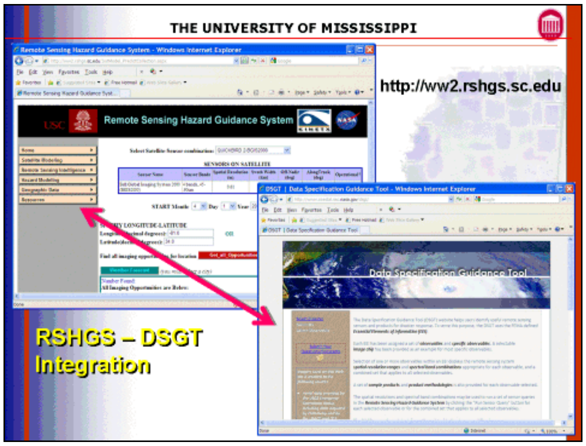
Essential Element of Information	Hurricane	Flood
Hurricane Forecasts and Related Information	X	
River Forecast and Flooding Information	X	X
Pre-Landfall Information	X	
Boundaries of the Primary and Secondary Disaster Area	X	X
Socio-Political-Economic Impacts – Residential	X	X
Socio-Political-Economic Impacts – Business	X	X
Socio-Political-Economic Impacts – Government	X	X
Jurisdictional Boundaries	X	X
Status of Transportation	X	X
Status of Communication Systems	X	X
Hazard-Specific Information	X	X
Status of Critical Infrastructure – Water	X	X
Status of Critical Infrastructure – Electrical Power	X	X
Status of Critical Infrastructure – Medical, Government, Educational	X	X
Hazardous, Toxic, and Radiological Issues	X	X











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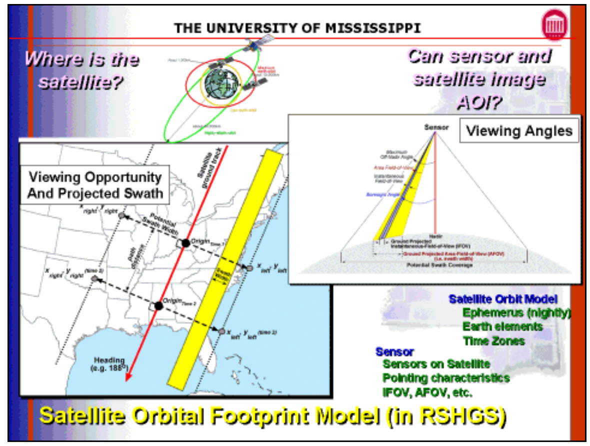
http://ww2.rshgs.sc.edu
Remote Sensing Hazard Guidance System
Data Specification Guidance Tool
RSHGS – DSGT Integration



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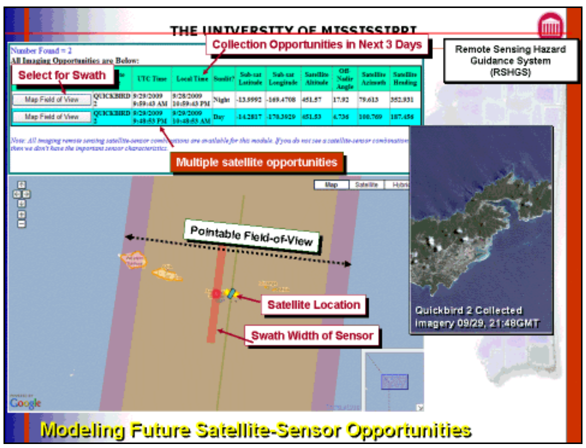
Where is the satellite?
Can sensor and satellite image AOI?
Viewing Angles
Viewing Opportunity And Projected Swath
Satellite Orbit Model
Ephemerus (nightly)
Earth elements
Time Zones
Sensor
Sensors on Satellite
Pointing characteristics
IFOV, AFOV, etc.
Satellite Orbital Footprint Model (in RSHGS)



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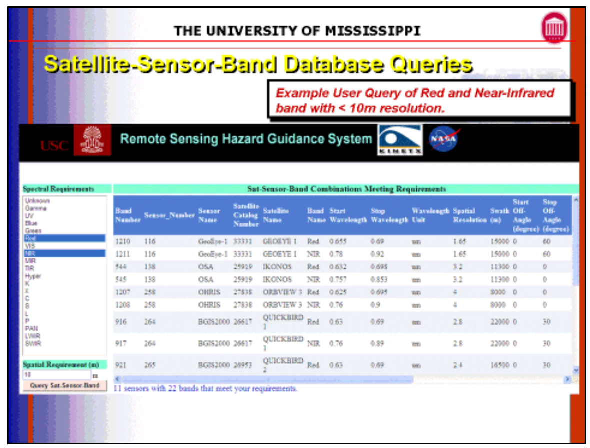
Collection Opportunities in Next 3 Days
Remote Sensing Hazard Guidance System (RSHGS)
Select for Swath
Multiple satellite opportunities
Pointable Field-of-View
Satellite Location
Swath Width of Sensor
Quickbird 2 Collected imagery 09/29, 21:48GMT
Modeling Future Satellite-Sensor Opportunities



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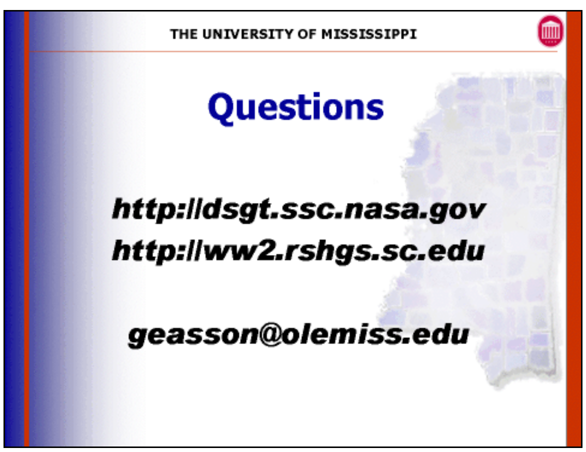
Satellite-Sensor-Band Database Queries
Example User Query of Red and Near-Infrared band with < 10m resolution.
Remote Sensing Hazard Guidance System



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Questions
http://dsgt.ssc.nasa.gov
http://ww2.rshgs.sc.edu
geasson@olemiss.edu

• • •

Andrew Zimmerman

Dr. Andrew Zimmerman is the President/CEO and cofounder of Civionics, LLC; he is also a postdoctoral research fellow in the Department of Civil and Environmental Engineering at the University of Michigan. Dr. Zimmerman has significant experience designing intelligent wireless sensing and distributed data processing systems, and he has published extensively in these areas. He holds M.S. and Ph.D. degrees in Civil & Environmental Engineering, as well as a M.S. degree in Computer Science & Engineering, all from the University of Michigan. While there, he was a recipient of the National Defense Science and Engineering Graduate Fellowship, the University of Michigan Rackham Predoctoral Fellowship, and the University of Michigan Greene Scholarship. In 2009, Dr. Zimmerman cofounded Civionics in an effort to move intelligent wireless solutions from the laboratory to industry.

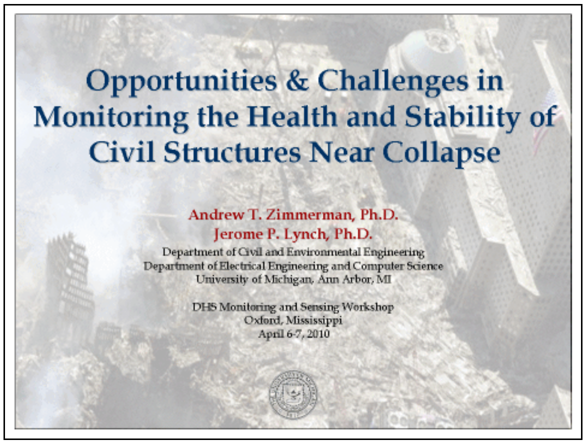
Jerome Lynch

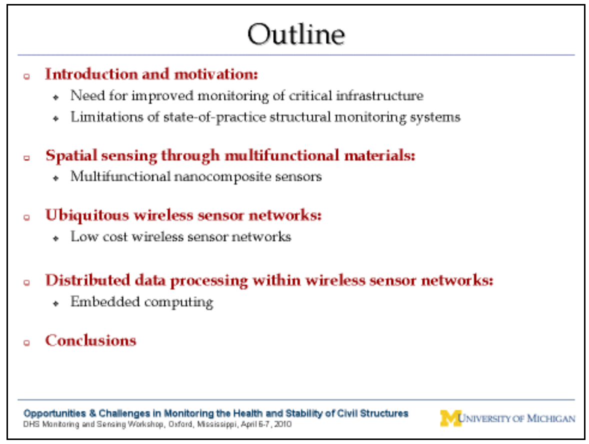
Dr. Jerome Lynch is an Associate Professor of Civil and Environmental Engineering at the University of Michigan; he is also a faculty member with the Department of Electrical Engineering and Computer Science. Dr. Lynch completed his graduate studies at Stanford University where he received his Ph.D. in Civil and Environmental Engineering in 2002, M.S. in Civil and Environmental Engineering in 1998, and M.S. in Electrical Engineering in 2003. Prior to attending Stanford, Dr. Lynch received his B.E. in Civil and Environmental Engineering from the Cooper Union. His current research interests are in the areas of wireless structural monitoring, feedback control, and damage detection algorithms. Some of Dr. Lynch's more current research has been focused on the design of nano-engineered materials for smart structure applications including carbon nanotube-based thin film wireless sensors for real-time structural health monitoring. Dr. Lynch was recently awarded the 2005 Office of Naval Research Young Investigator Award, 2007 University of Michigan Henry Russel Award, 2008 College of Engineering (University of Michigan) 1938E Award, and 2009 NSF CAREER Award.

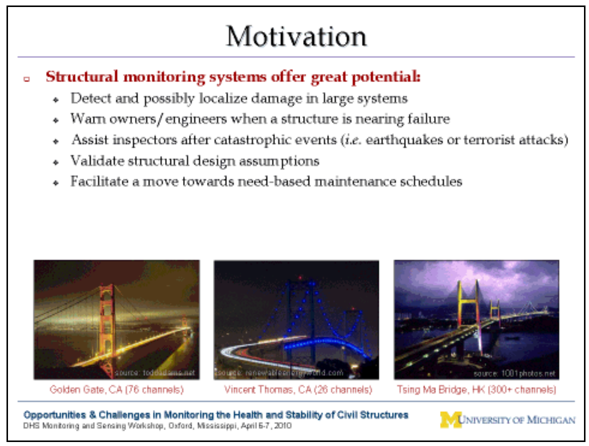
Opportunities and Challenges in Monitoring the Health and Stability of Civil Structures Near Collapse

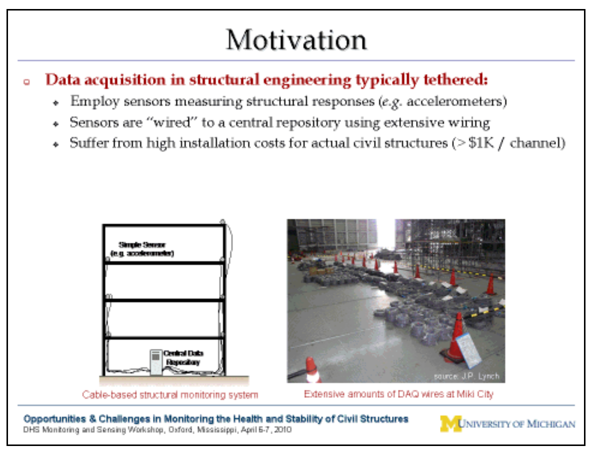
Critical infrastructure systems, including government buildings, bridges, tunnels, pipelines, dams and levees, remain vulnerable to man-made hazards including improvised explosive devices detonated by terrorists. Current approaches to infrastructure protection largely focus on prevention and structural strengthening. However, after a terrorist explosion occurs, there is a dire need to rapidly assess the condition of the structure, quantify its stability, determine the extent of fire and identify the location of structural inhabitants. This presentation explores the opportunities that exist in deploying monitoring system technologies to provide real-time data and information to emergency first responders that are responsible for securing the structure and removing surviving inhabitants, all while ensuring the safety of first-responders. Sensors for infrastructure monitoring during and after a terrorist event can be divided into three broad categories: 1) sensors for structural assessment; 2) sensors to monitor fire conditions (e.g., temperature and gases); and 3) sensors to identify and track inhabitants. This presentation highlights the sensors that currently exist in addition to identifying opportunities to create new sensors that can meet the unique and challenging demands of the application's environment (i.e., extreme shock and heat loads).

Presentation Slides









SESSION 6

THE FUTURE OF SENSING

Motivation for Today's Talk

- **As structural monitoring systems gain popularity, improved methods of collecting, storing, and managing sensor data are needed:**

A. Increased sensor density is needed to provide meaningful data
Spatial sensing through multifunctional sensing skins
Ubiquitous wireless sensing networks

B. Automated methods are required to analyze large amounts of data
Distributed data processing within wireless sensor networks

Golden Gate, CA (76 channels) — Vincent Thomas, CA (26 channels) — Tsing Ma Bridge, HK (300+ channels)

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Outline

- **Introduction and motivation:**
  - Need for improved monitoring of critical infrastructure
  - Limitations of state-of-practice structural monitoring systems
- **Spatial sensing through multifunctional materials:**
  - Multifunctional nanocomposite sensors
- **Ubiquitous wireless sensor networks:**
  - Low cost wireless sensor networks
- **Distributed data processing within wireless sensor networks:**
  - Embedded computing
- **Conclusions**

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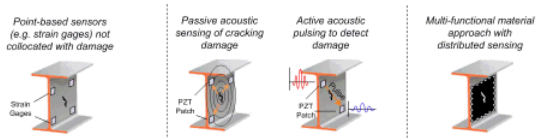
Distributed Sensing for SHM

- **Emergence of distributed sensor technologies:**
  - Point sensors lack sensitivity to damage
  - Promising spatial sensors for health monitoring:
    - AE, ultrasonic (pitch-echo and pitch-catch), sensing skins



Current Approach
- Indirect point sensing
- Insensitivity away from damage
- Density can be expensive

Passive and Active SHM Strategy
- Passive AE requires interpretation
- Active sensing requires multiple high power transducers for spatial mapping

Proposed Approach
- True distributed mapping
- Multifunctional CNT-based thin film appliqué

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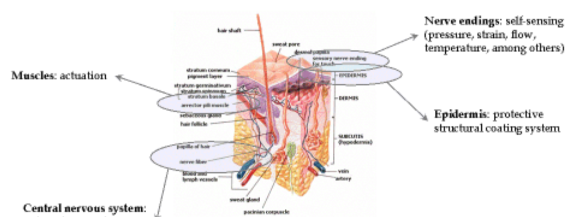
Biomimetic Multifunctional Materials

- **Design of biomimetic multifunctional materials**
  - Component-based damage detection paradigm
  - Self-sensing, actuation, energy harvesting, self-healing, among others



Human skin as a multifunctional material

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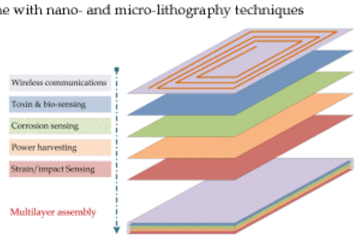
Multifunctional Sensing Transducers

- **Biomimetic multifunctional active coating systems:**
  - Layer-by-layer permits 2.5-dimensional nano- and macro-structuring
  - Micro- and nano-fabrication patterning techniques
  - Integrate with existing structural coating systems
  - Combine with nano- and micro-lithography techniques



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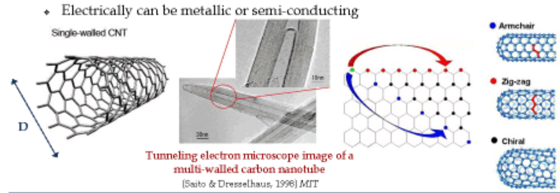
Carbon Nanotubes

- **Single-walled carbon nanotubes (SWNT):**
  - Rolled cylindrical structures with C atoms double-bonded (C=C)
  - Oriented hexagonally on the surface
  - Diameter (D): 0.4 ~ 10.0 nm
  - Impressive mechanical strength: ~200 times stronger (σ_T), 5 times stiffer (E) than steel
  - High aspect ratio (10^4 ~ 10^6) for scaffolding
  - Electrically can be metallic or semi-conducting



Tunneling electron microscope image of a multi-walled carbon nanotube
(Saito & Dresselhaus, 1998) *MIT*

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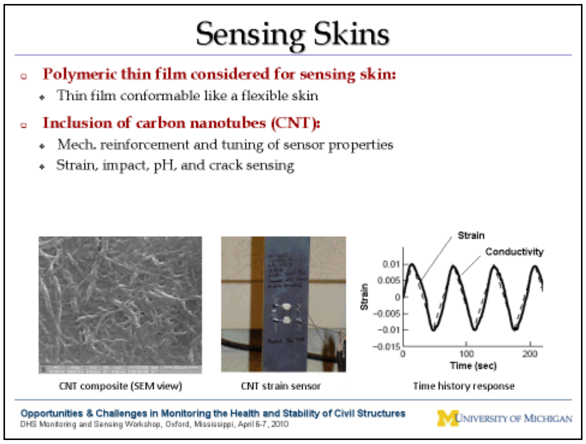
Sensing Skins
Polymeric thin film considered for sensing skin:
Thin film conformable like a flexible skin
Inclusion of carbon nanotubes (CNT):
Mech. reinforcement and tuning of sensor properties
Strain, impact, pH, and crack sensing
Strain
Conductivity
Time (sec)
CNT composite (SEM view)
CNT strain sensor
Time history response
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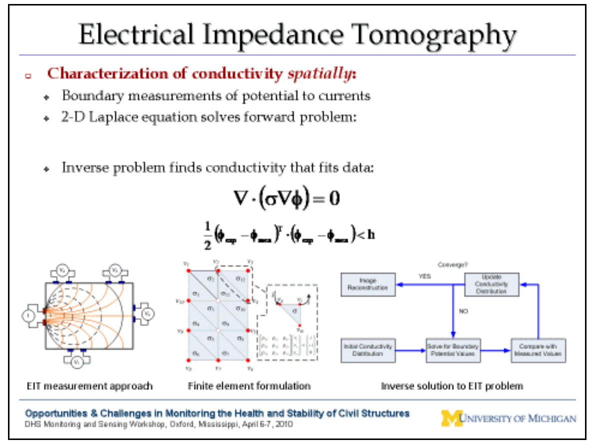
Electrical Impedance Tomography
Characterization of conductivity spatially:
Boundary measurements of potential to currents
2-D Laplace equation solves forward problem:
Inverse problem finds conductivity that fits data:
$\nabla \cdot (\sigma \nabla \phi) = 0$
$\frac{1}{2}(\phi_{exp} - \phi_{meas})^T \cdot (\phi_{exp} - \phi_{meas}) < h$
EIT measurement approach
Finite element formulation
Inverse solution to EIT problem
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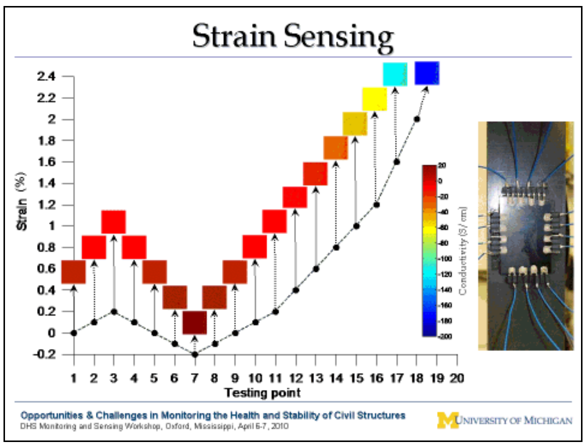
Strain Sensing
Strain (%)
Testing point
Conductivity (S/cm)
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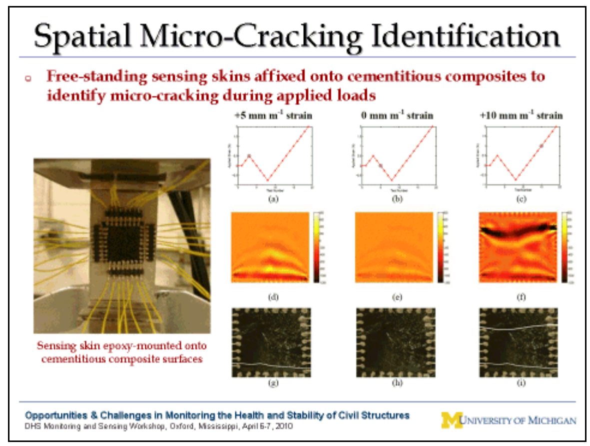
Spatial Micro-Cracking Identification
Free-standing sensing skins affixed onto cementitious composites to identify micro-cracking during applied loads
+5 mm m⁻¹ strain
0 mm m⁻¹ strain
+10 mm m⁻¹ strain
Sensing skin epoxy-mounted onto cementitious composite surfaces
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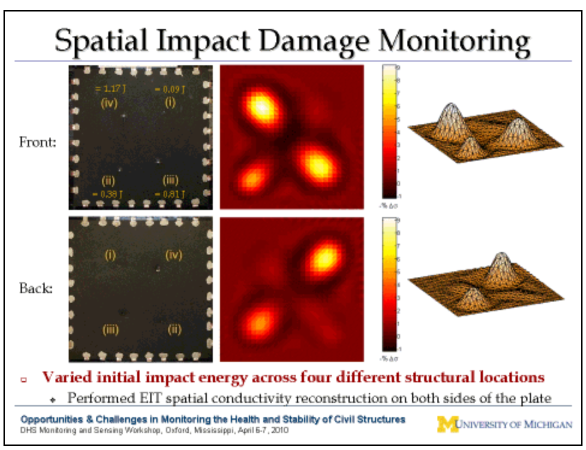
Spatial Impact Damage Monitoring
Front:
Back:
Varied initial impact energy across four different structural locations
Performed EIT spatial conductivity reconstruction on both sides of the plate
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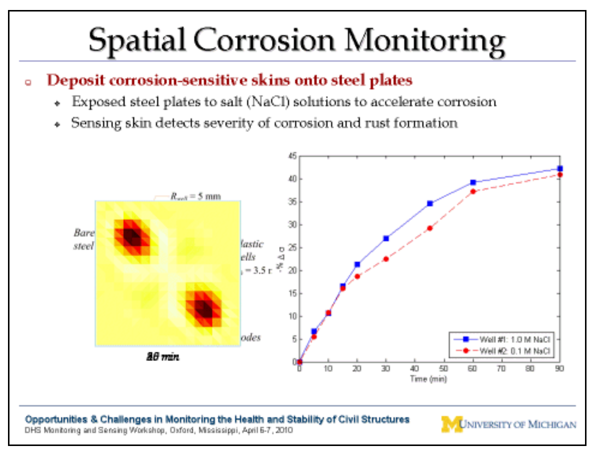
Spatial Corrosion Monitoring
Deposit corrosion-sensitive skins onto steel plates
Exposed steel plates to salt (NaCl) solutions to accelerate corrosion
Sensing skin detects severity of corrosion and rust formation
Time (min)
Well #1: 1.0 M NaCl
Well #2: 0.1 M NaCl
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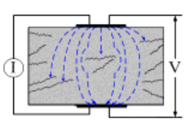
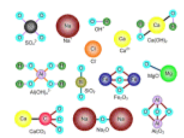
Cement as a Multifunctional Material

- **Cements materials are semi-conducting materials:**
  - Bulk resistivities around $10^3 \sim 10^8$ Ω-cm
  - Primary electric carriers are ions (not electrons as is the case with metals)
  - Ions mobile in pore water within the cement matrix
- **Resistivity as a sensing functionality:**
  - Hydration monitoring (laboratory and field)
  - Composition assessment (laboratory)
  - Measure mechanical state including damage (emerging)



Electrical testing of cement specimen


Chemical atoms and compounds in cement

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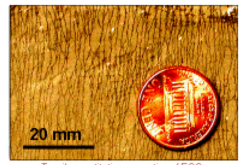
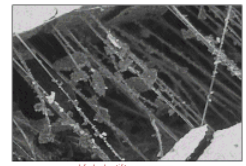
Engineered Cementitious Composites

- **High performance fiber reinforced cement composites (HPFRCC):**
  - Viable alternative when highly ductile behavior is sought
  - Engineered cementitious composites (ECC)
- **Engineering cementitious composites:**
  - Strain hardening in tension due to inclusion of polymeric fibers
  - Energy dissipation in tension through the formation of micro-cracks





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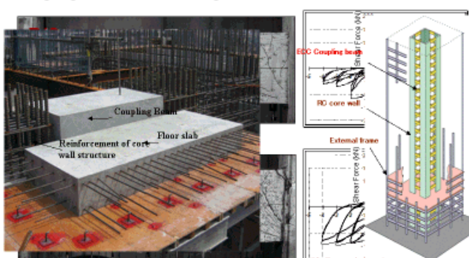
ECC Adoption

- **ECC has been widely used in a number of large-scale structures:**
  - Bridge decks – thin deck and link slab elements
  - Coupling beams in tall building structures



Source: Fukuyama, et al. 2000
41-story Nabeaure Yokohama Tower (Kajima, Japan)

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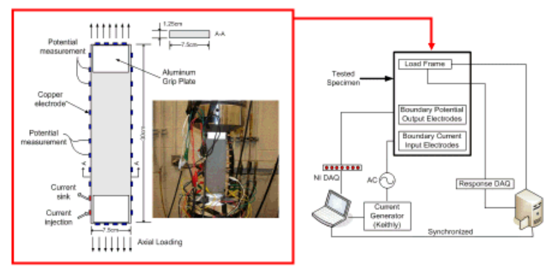
Conductivity Mapping Investigation Strategy



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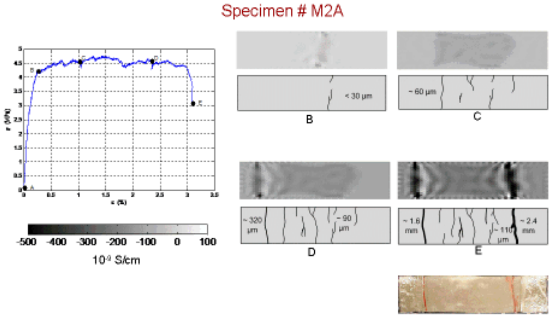
Conductivity Mapping during Strain Hardening

Specimen # M2A



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Current EIT Devices

- **Two types of EIT systems used in medical imaging:**
  - Single Source:
    - Examples:
      - Maltron Sheffield series
      - Russian Academy of Science
    - Issues:
      - Low variability and control
  - Multiple Source:
    - Examples:
      - Oxford Brookes series
      - Rensselaer ACT series
    - Issues:
      - Size and power usage


Maltron Sheffield MK3.5
(*Image courtesy of maltronint.com*)

...rce	Type	Electrodes	Frequency	Amplitude
...gle	Current	16	50 kHz	5 mA
...gle	Current	16	20 kHz	5 mA
...gle	Current	16	8:9.6 kHz-1.2 MHz	1 mA
...gle	Current	8	30:2 kHz-1.6 MHz	850 uA
...gle	Current	16	8 kHz	.5 mA
...gle	Current	256	50 kHz, 110 kHz	.5 mA
...iple	Voltage	32	9.6 kHz	4096:0-5 V
...iple	Current	64	10, 40, 160 kHz	Variable
...iple	Both	<2048	<40 MHz	Variable
...iple	Current	32	28.8 kHz	Variable
Rensselaer ACT... Multiple	Both	<72	300 Hz-1 MHz	Variable

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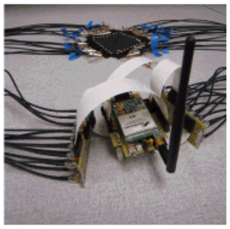
Wireless EIT Sensor for SHM Applications

- **Multipurpose sensor for multifunctional materials:**
  - EIT for spatial mapping of material conductivity
  - Impedance spectroscopy of piezoelectric materials
- **Proposed device:**
  - Current injection:
    - Precise control at high-frequencies
  - Multiplexing:
    - 32 channels for current and voltage
  - Measurement:
    - Low-noise A/D conversion
  - Compact design for portability
  - Low-power for battery operation
  - Wireless telemetry



EIT Device Layout

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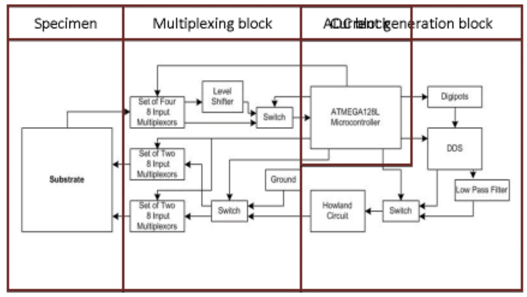
Wireless EIT Device Architecture

Functional overview of portable EIT device for structural health monitoring:



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Outline

- **Introduction and motivation:**
  - Need for improved monitoring of critical infrastructure
  - Limitations of state-of-practice structural monitoring systems
- **Spatial sensing through multifunctional materials:**
  - Multifunctional nanocomposite sensors
- **Ubiquitous wireless sensor networks:**
  - Low cost wireless sensor networks
- **Distributed data processing within wireless sensor networks:**
  - Embedded computing
- **Conclusions**

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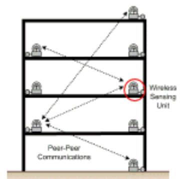
Wireless Structural Monitoring

- **Three innovations associated with wireless sensors:**
  1. Wireless communication - peer-to-peer and ad-hoc communication
  2. Cost – low cost nodes drives higher densities of sensors
  3. Computing - collocation of computing facilitates sensor-based interrogation



Wireless structural monitoring system

Numerous wireless sensor platforms

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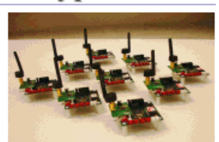
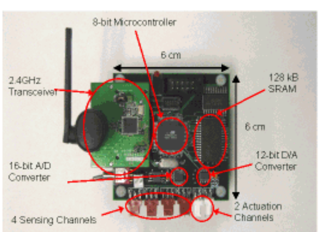
Wireless Sensor Prototype

- **Compact wireless sensor prototype:**
  - 16-bit ADC resolution on 4 channels
  - Enhanced range 802.15.4 radio (300 m)
  - Integration of 12-bit actuation interface



Completed Wireless Sensor Network



SPECIFICATIONS	
Cost	$175 per unit
Form Factor	5 cm x 6 cm x 2 cm
Energy Source	5 AA Batteries
Power	40 mA @ 5V
Range	50-300 m
Data Rate	250 Kbps
Sample Rate	10 kHz

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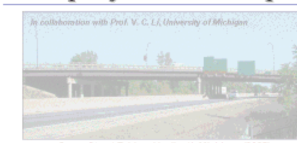
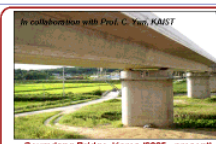
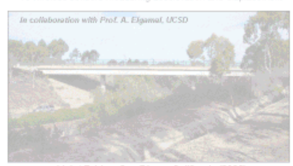
Deployments to Operational Structures



Grove Street Bridge, Ypsilanti, Michigan (2006)
18 wireless sensors measuring acceleration and displacement



Geumdang Bridge, Korea (2005 - present)
16 wireless sensors measuring acceleration



Voigt Bridge, San Diego, California (2006)
20 wireless sensors measuring acceleration

Wu Yuan Bridge, China (2005 - present)
8 wireless sensors measuring acceleration

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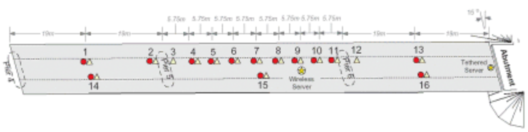
SESSION 6
THE FUTURE OF SENSING

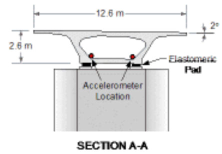
Instrumentation Strategy



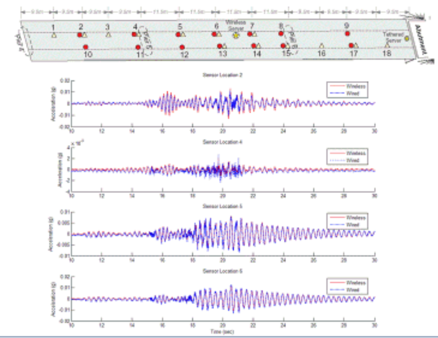
Accelerometers for Structural Monitoring

Sensor Property	PCB393* Piezoelectric (Cable System)	PCB3801 MEMS Capacitive (Wireless System)
Range	± 1 g	± 3 g
Sensitivity	10 V/g	0.7 V/g
Bandwidth	2000 Hz	80 Hz
RMS Noise Floor	20 μg	0.5 mg
Dynamic Range	111 dB	95 dB

** Amplified by a factor of 10*

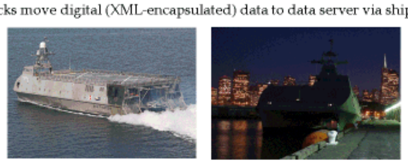


Forced Dynamic Response to Trucks



FSF-1 SeaFighter

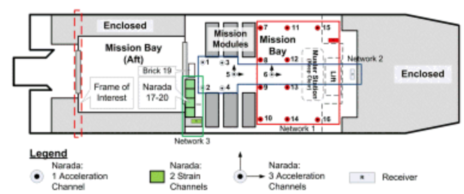
- **Instrumentation of FSF-1 SeaFighter high-speed aluminum catamaran:**
  - Opportunity to test a wireless hull monitoring system
  - Existing wired hull monitoring system allows wireless data to be validated
  - Ship transit from Panama City, FL to Portland, OR (May-June 2008)
- **Scientific Payload Data Acquisition System (SPDAS):**
  - Strain gauges connected to bricks using "stamp" bridge modules
  - Accelerometers (6-DOF ship motion) and TSK wave height sensor connected
  - Bricks move digital (XML-encapsulated) data to data server via ship LAN



FSF-1 SeaFighter High-Speed Aluminum Catamaran Vessel

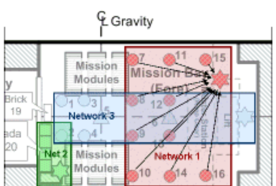
Wireless Hull Monitoring System

- **A 28-channel wireless hull monitoring system installed in April 2008:**
  - 8 metal foil strain gauges (split from the SPDAS system)
  - 2 triaxial accelerometers (Crossbow CXL02TG3)
  - 14 uniaxial accelerometers (Crossbow CXL02LF1Z)
  - Data collected using 20 Narada wireless sensors



Wireless Hull Monitoring System

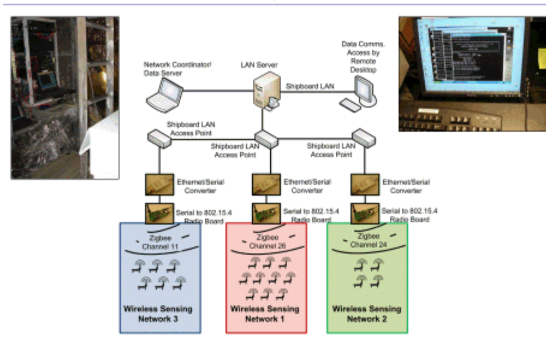
- **Wireless monitoring system designed for continuous data collection:**
  - Streaming 28 channels (at 100 Hz or greater) would exceed bandwidth
  - Decompose monitoring system into three wireless sub-networks
  - Sub-networks are connected to one-another by fiber-optic ship LAN
  - *Automated* system operation by a data server located below deck



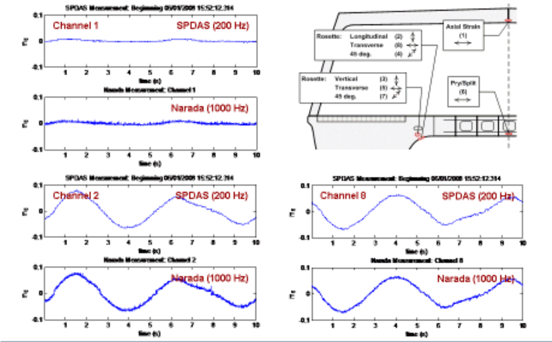
Narada installation in ship mission bay

SeaFighter mission bay

Tiered Wireless/Wired Network



Strain Time Histories



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  - Limitations of state-of-practice structural monitoring systems
- **Spatial sensing through multifunctional materials:**
  - Multifunctional nanocomposite sensors
- **Ubiquitous wireless sensor networks:**
  - Low cost wireless sensor networks
- **Distributed data processing within wireless sensor networks:**
  - Embedded computing
- **Conclusions**

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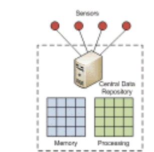
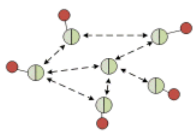
University of Michigan

In-Network Data Processing

- **What sets wireless sensors apart is embedded computing at the sensor:**
  - Each sensing node has independent memory and processing cores.
  - However, each node is individually much less powerful than a modern PC.
  - Energy-efficient to interrogate data at the sensor than communicate raw data.
- **Scalable implementation must embrace distributed computing:**
  - Minimize communication to save energy and minimize data loss.
  - Parallel computing to offer speed and scalability to high nodal counts.



Tethered structural monitoring system



Wireless structural monitoring system

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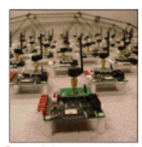
Why In-Network Processing?

- **What sets wireless sensors apart is embedded computing at the sensor:**
- **System scalability:**
  - Streaming raw data is not scalable since it would exhaust bandwidth.
  - Higher communication demand erodes the wireless channel performance.
- **Power management:**
  - Communication is power-intensive - critical issue for battery powered nodes.
- **Data management:**
  - Avoidance of data inundation at the central repository.



Dense wireless sensor networks

Demand for power efficiency

Avoidance of data inundation

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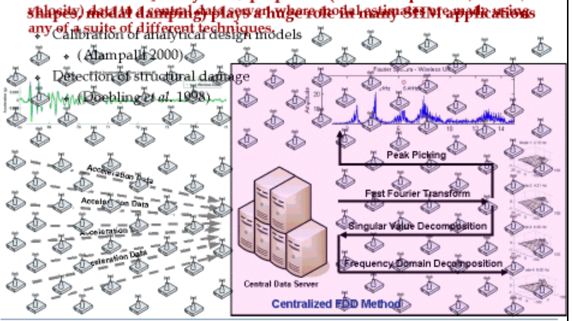
Distributed Computing Example

- **The identification of dynamic properties (modal frequencies, mode shapes) and modal damping plays a huge role in many SHM applications**
  - Calibration of analytical design models (Alampalli 2000)
  - Detection of structural damage (Doebling *et al.* 1998)



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Distributed Computing Platform

- **Wireless sensor networks are a very unique computing platform:**
  - Small memory and computing footprint at each sensor node
  - Significant memory and data processing ability within the network
  - Advantages include reduction of data glut and system power efficiencies

Embedded Wireless Sensor Software Library for Structural Health Monitoring

Embedded Algorithm	Embedded Application
Fast Fourier Transform	Modal analysis
Peak picking algorithm	Mode shape determination
Frequency domain decomp.	Mode shape determination
AR, ARMA, ARX time series	Structural health monitoring
Bayesian classifiers	Structural health monitoring
State-space control	Structural control
Cable tension force estimation	System identification
Simulated annealing	Parallel model updating

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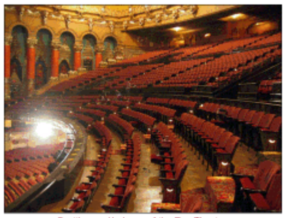
SESSION 6

THE FUTURE OF SENSING

Fox Theatre

- **Fox Theatre, Detroit, Michigan:**
  - 2nd largest theatre in U.S.
  - Cantilevered main balcony
  - Humanly perceptible vibrations
  - Assess modal features of structure



Cantilevered balcony of the Fox Theatre

Fox Theatre, Detroit, Michigan

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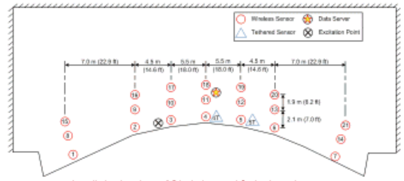
Instrumentation Strategy

Tethered DAQ system recording channels — Wireless sensor with amplification circuitry — MEMS and piezoelectric accelerometers — Heel-drop tests simulate impulse loading to balcony



Installation locations of 21 wireless and 2 wired accelerometers

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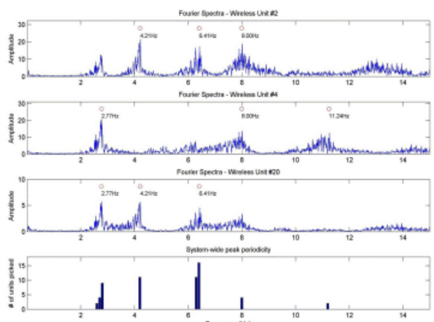
PP Frequency Results



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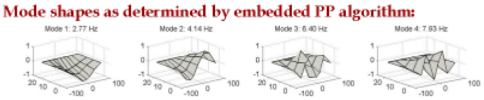
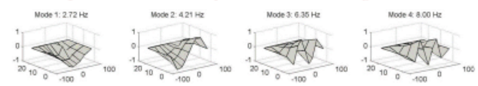
PP and FDD Mode Shapes

- **Mode shapes as determined by embedded PP algorithm:**



- **Mode shapes as determined by embedded FDD algorithm:**



Accurate frequency estimates

Method	Run #	Natural Frequency (Hz) Mode 1	Mode 2	Mode 4	Mode 5	MAC Mode 1	Mode 2	Mode 4
Centralized FDD (off-line)	1	2.734	4.163	6.335	7.946	1.000	1.000	1.000
Peak Picking (embedded)	2	2.727	4.210	6.349	7.996	-	0.949	0.937
	3	2.734	4.155	6.342	8.020	0.825	0.678	0.427
	4	2.772	4.144	6.396	7.929	0.990	0.975	0.869

Accurate mode shape estimates

Method	Run #	MAC Mode 1	Mode 2	Mode 4
Centralized FDD (off-line)	1	1.000	1.000	1.000
Decentralized FDD (embedded)	5	0.957	0.985	0.961
	6	0.966	0.945	0.821
	7	0.994	0.984	0.630

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Communications Requirements

- **Agent-based approach requires much less communication:**
  - Improves scalability, power requirements, etc.

Method	Transmission	Payload Type	Bytes	Results	Assumption
Centralized Server	4096 shorts x 20node	Time history data to server from each node	163,840	{σ}	
	4 floats x 20 nodes	4 damping ratios from server to each node	320	{ξ}	
	80 floats x 20 nodes	4 mode shapes from server to each node	6,400	{φ}	
	4 floats x 20 nodes	4 frequencies from server to each node	320	{f}	
		TOTAL	170,880		
Decentralized Peak Picking (PP)	4 floats x 19 nodes	4 frequency peaks to central node	304	{f}	
	4 floats x 19 nodes	4 modal frequencies back each node	304	{f}	
	4 float x 20 x 19 nodes	Imaginary components with each node (20) sending to every other node (19)	1,520	{φ}	
		TOTAL	2,128		
Decentralized FDD	8 floats x 19 nodes	Spectral value at each mode from one node to a neighboring node	608	A(ω)	Modal frequencies already known
	8 floats x 18 nodes	2 node mode shape to central node	576	{φ}	
	80 float x 19 nodes	4 stitched mode shapes back to each node	6,080	{φ}	
		TOTAL	7,264		
Decentralized Random Decrement (RD)	4 floats x 19 nodes	4 identified frequencies to central node	304	{f}	Modal frequencies already known
	4 floats x 19 nodes	4 identified damping ratios to central node	304	{ξ}	
	4 floats x 19 nodes	4 modal frequencies back each node	304	{f}	
	4 floats x 19 nodes	4 modal damping ratios back each node	304	{ξ}	
		TOTAL	1,216		

NOTE: short = 2 bytes; float = 4 bytes

Centralized

Agent-based

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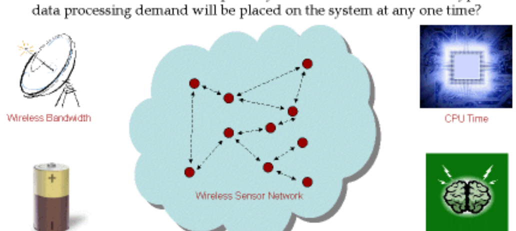
Scarce Resource Allocation

- **Many limited resources distributed throughout the wireless network:**
  - All of these resources impact the performance of the sensor network.
  - How do we distribute them optimally when we don't know what types of data processing demand will be placed on the system at any one time?



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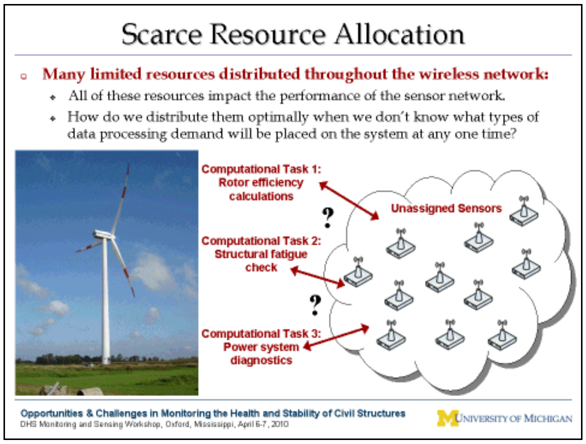

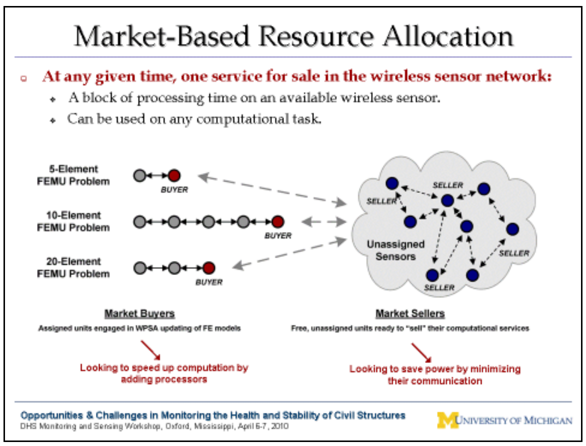

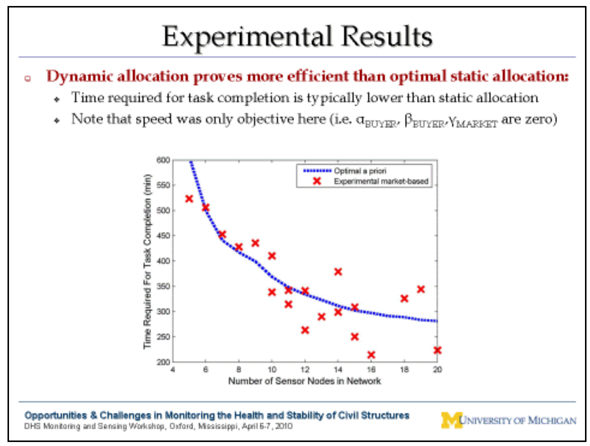

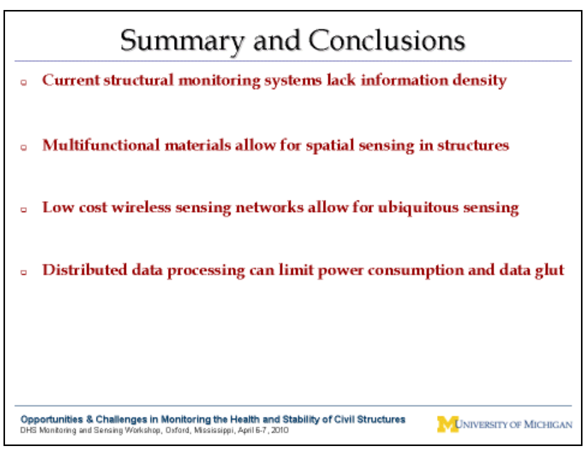

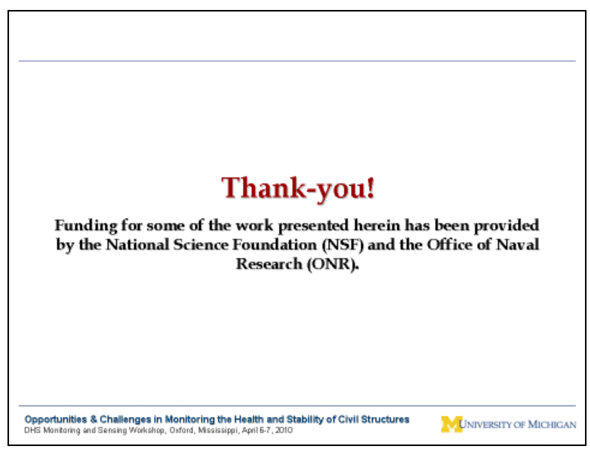

• • •

Earle Kennett

As Chief Operating Officer of the National Institute of Building Sciences, Earle Kennett is responsible for and oversees all Institute technical programs and is the organization's second in command. Prior to becoming the Institute Chief Operating Officer, he managed and directed hundreds of projects for Federal agencies in building science, architecture, and engineering as Vice President at the National Institute of Building Sciences (NIBS) and past Administrator for Research for the American Institute of Architects (AIA).

He presently manages a number of technical programs including, contracts with the Department of Veterans Affairs, NASA, Department of Energy, the Department of Defense, the Naval Facilities Engineering Command, the Army Corps of Engineers, the Air Force, the Department of Homeland Security, Department of Education, Federal Emergency Management Agency, and the General Services Administration. The buildingSMART Alliance, the National CAD Standard, the National BIM Standard, ProjNet(sm), the Building Enclosure Technology and Environmental Council (BETEC), the High Performance Building Council (HPBC), the Facility Maintenance and Operations Committee (FMOC), Construction Operations Building Information Exchange (COBIE), Specifier's Product Information Exchange (SPiE), and the National Clearinghouse for Educational Facilities (NCEF) are under his direction.

He also manages a program concerned with incorporating a large number of design and construction criteria on a Web site. This system, the Whole Building Design Guide (WBDG) is an innovative concept in information use in the construction industry. The system presently has over 250,000 users and over 2 million documents downloads on a monthly basis, involves over 15 Federal agencies, and has become the sole portal for the distribution of uniform facility criteria for the military services.

He has taught a range of technical architectural courses at the University of Maryland, Florida A&M University, and the Washington-Alexandria Center for Virginia Polytechnic Institute and State University.

In 1976 he received his bachelor of architecture with highest honors from the School of Architecture at the University of Tennessee, where he received the Chancellor's Citation for Extraordinary Academic Achievement. He also has a bachelor of engineering from Memphis State University.

BIM Basics and Utilization for Building Stabilization Efforts

Building Information Modeling (BIM) is emerging to be an important tool for all building stakeholders. It can be an invaluable tool for emergency managers after an IED attack that causes buildings to be in a near-collapse condition. This presentation offers some basics of BIM and also explores the ways that BIM can help emergency managers.

Presentation Slides

National Institute of BUILDING SCIENCES

The buildingSMART alliance - BIM Overview:

Overview, Interoperability and Collaboration

buildingSMARTalliance

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"BIM changes everything"

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2

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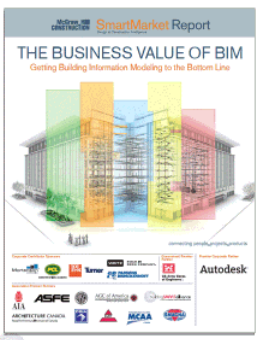
The Business Value of BIM



- Released September 22, 2009
- Available from buildingSMART alliance web site
- New McGraw-Hill Construction web site

bim.construction.com/research

- Providing location for case studies
- Surveyed over 4,000 – 2,228 completed surveys (95% confidence – 5% error)

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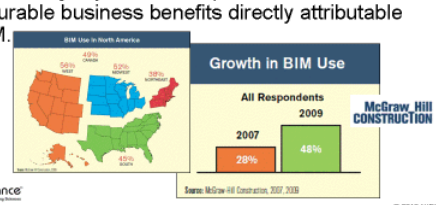
Adoption of BIM Software

- **Key research findings include:**
  - Almost 50% of the industry is now using BIM
  - 20% of non-users plan to adopt with 2 years
  - All BIM users plan significant increases in their use
  - The vast majority of users experience measurable business benefits directly attributable to BIM.



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Desired Outcome of BIM

1. Collect data once and use from inception onward and allow information to flow
   - Authoritative source collects information and records metadata
   - Information assurance is in place to protect intellectual property
   - Multi faceted analysis is supported by software
   - Facility management uses information for operations and sustainment
   - All facets of the lifecycle are supported

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Desired Outcome of BIM

2. Build facilities electronically and completely before we build them physically. "Build a model then build the model"
   - Reduces risk and therefore litigation
   - Reduces RFI's and change orders
   - Allows more activities to occur in parallel thus speeding delivery
   - Provides better estimates
   - Delivers true as-built

Courtesy Dennis Shelden – Gehry Technologies

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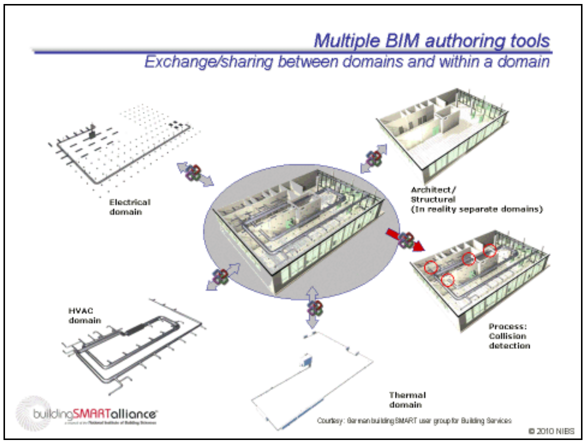

Multiple BIM authoring tools
Exchange/sharing between domains and within a domain
Electrical domain
Architect/ Structural (In reality separate domains)
HVAC domain
Process: Collision detection
Thermal domain
Courtesy: German buildingSMART user group for Building Services
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Truly The Big Picture
Cost of design
Cost of construction
Cost of Ops & Sustainment
Cost of People or Process
Design has a major affect on the value of the product or service produced. However we do not have a good feedback loop to assess the impact of our decisions – 3.8% improvement pays for facility
Value of Product or Service
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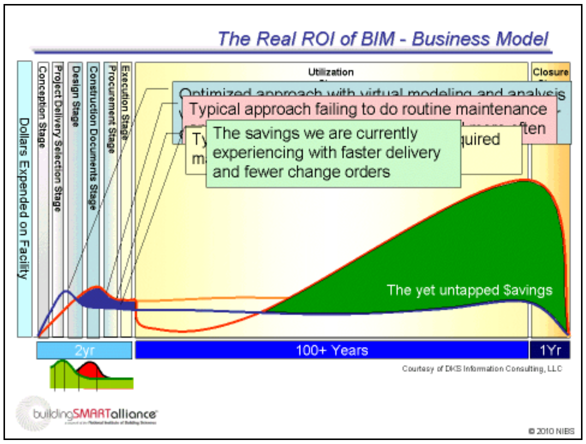

The Real ROI of BIM - Business Model
Dollars Expended on Facility
Conception Stage
Project Delivery Selection Stage
Design Stage
Construction Documents Stage
Procurement Stage
Execution Stage
Utilization
Closure
Typical approach failing to do routine maintenance
The savings we are currently experiencing with faster delivery and fewer change orders
The yet untapped $avings
2yr
100+ Years
1Yr
Courtesy of DKS Information Consulting, LLC
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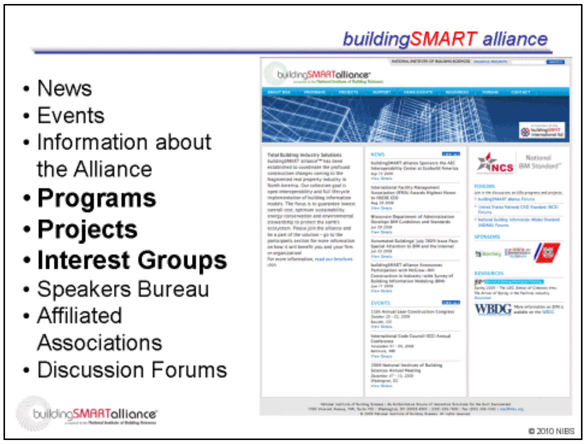

buildingSMART alliance
• News
• Events
• Information about the Alliance
• Programs
• Projects
• Interest Groups
• Speakers Bureau
• Affiliated Associations
• Discussion Forums
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States Requiring BIM
State of Wisconsin - Department of ADMINISTRATION
Division of State Facilities
Division of State Facilities
Master Specifications/Design Guidelines
DSF BIM Guidelines & Standards
Texas Facilities Commission
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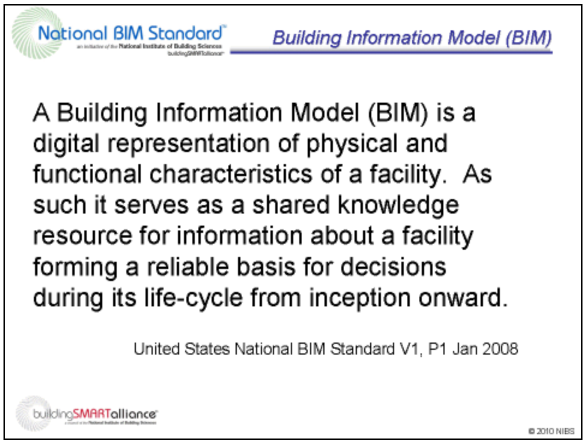

National BIM Standard
Building Information Model (BIM)
A Building Information Model (BIM) is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle from inception onward.
United States National BIM Standard V1, P1 Jan 2008
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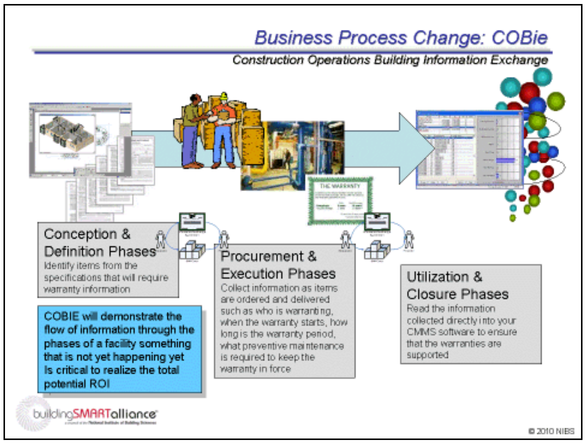

Business Process Change: COBie
Construction Operations Building Information Exchange
Conception & Definition Phases
Identify items from the specifications that will require warranty information
COBIE will demonstrate the flow of information through the phases of a facility something that is not yet happening yet Is critical to realize the total potential ROI
Procurement & Execution Phases
Collect information as items are ordered and delivered such as who is warranting, when the warranty starts, how long is the warranty period, what preventive maintenance is required to keep the warranty in force
Utilization & Closure Phases
Read the information collected directly into your CMMS software to ensure that the warranties are supported
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Maintaining Information Must Be Part of Doing Business
Product Selection
Analysis
Ordering & Invoicing
Maintain COBIE
Close Work Order When Model is Updated
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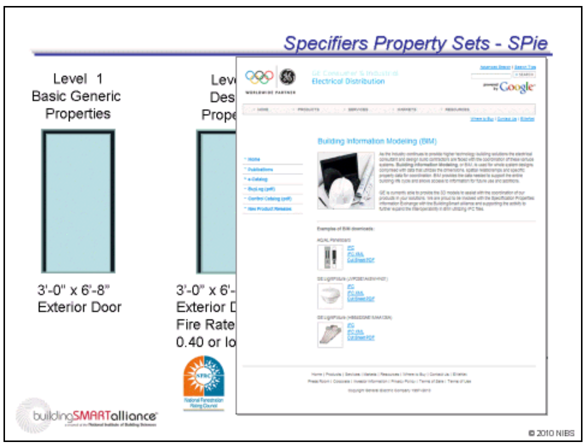

Specifiers Property Sets - SPie
Level 1
Basic Generic Properties
3'-0" x 6'-8"
Exterior Door
Building Information Modeling (BIM)
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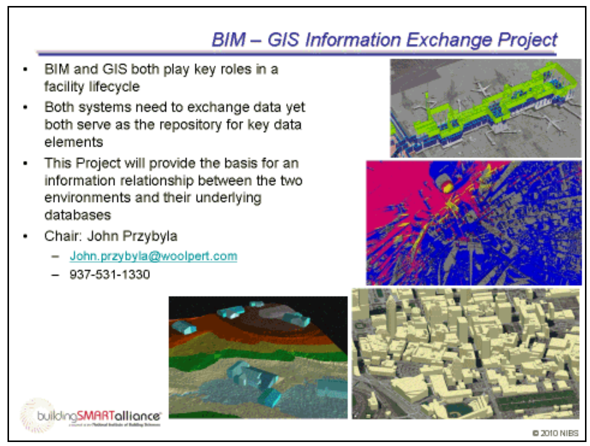

BIM – GIS Information Exchange Project
• BIM and GIS both play key roles in a facility lifecycle
• Both systems need to exchange data yet both serve as the repository for key data elements
• This Project will provide the basis for an information relationship between the two environments and their underlying databases
• Chair: John Przybyla
– John.przybyla@woolpert.com
– 937-531-1330
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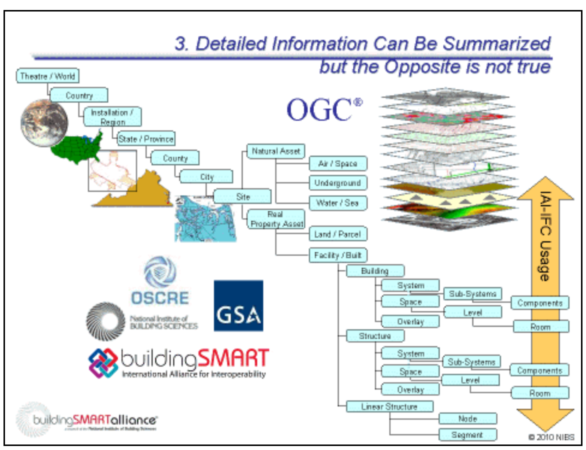

3. Detailed Information Can Be Summarized but the Opposite is not true
Theatre / World
Country
Installation / Region
State / Province
County
City
Site
Natural Asset
Air / Space
Underground
Water / Sea
Real Property Asset
Land / Parcel
Facility / Built
Building
System
Space
Overlay
Structure
Sub-Systems
Level
Components
Room
Linear Structure
Node
Segment
OGC®
OSCRE
National Institute of BUILDING SCIENCES
GSA
buildingSMART
International Alliance for Interoperability
IAI-IFC Usage
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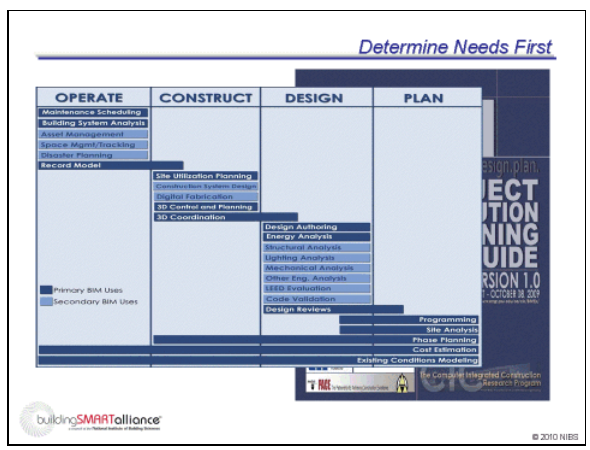

Determine Needs First
OPERATE
CONSTRUCT
DESIGN
PLAN
Maintenance Scheduling
Building System Analysis
Asset Management
Space Mgmt/Tracking
Disaster Planning
Record Model
Site Utilization Planning
Construction System Design
Digital Fabrication
3D Control and Planning
3D Coordination
Design Authoring
Energy Analysis
Structural Analysis
Lighting Analysis
Mechanical Analysis
Other Eng. Analysis
LEED Evaluation
Code Validation
Design Reviews
Programming
Site Analysis
Phase Planning
Cost Estimation
Existing Conditions Modeling
Primary BIM Uses
Secondary BIM Uses
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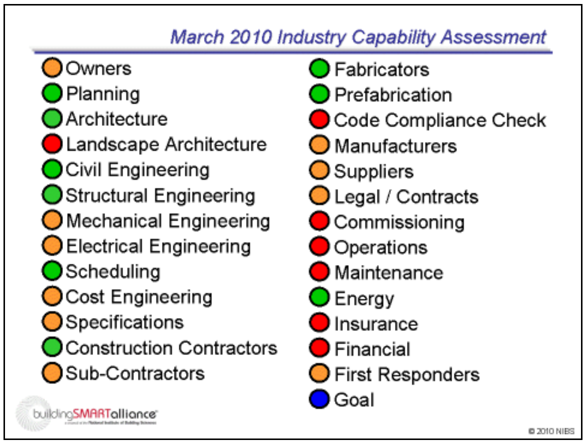
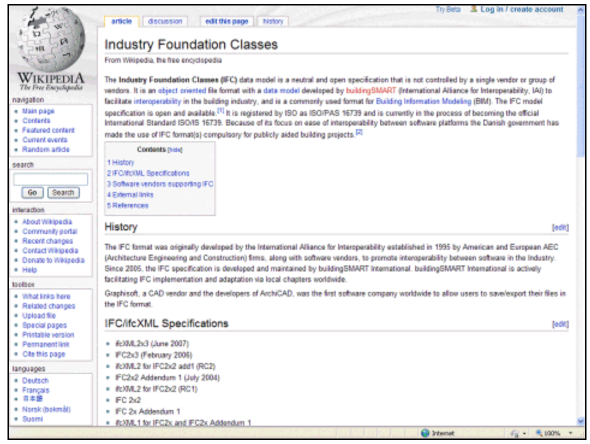




Industry Foundation Classes

From Wikipedia, the free encyclopedia

The **Industry Foundation Classes** (IFC) data model is a neutral and open specification that is not controlled by a single vendor or group of vendors. It is an object oriented file format with a data model developed by buildingSMART (International Alliance for Interoperability, IAI) to facilitate interoperability in the building industry, and is a commonly used format for Building Information Modeling (BIM). The IFC model specification is open and available.[1] It is registered by ISO as ISO/PAS 16739 and is currently in the process of becoming the official International Standard ISO/IS 16739. Because of its focus on ease of interoperability between software platforms the Danish government has made the use of IFC format(s) compulsory for publicly aided building projects.[2]

Contents [hide]
1 History
2 IFC/ifcXML Specifications
3 Software vendors supporting IFC
4 External links
5 References

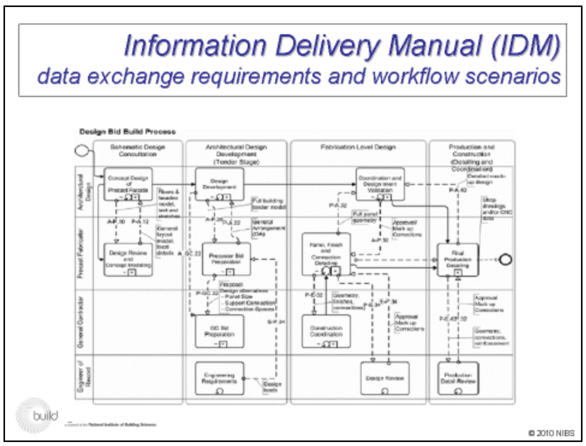
History [edit]

The IFC format was originally developed by the International Alliance for Interoperability established in 1995 by American and European AEC (Architecture Engineering and Construction) firms, along with software vendors, to promote interoperability between software in the Industry. Since 2005, the IFC specification is developed and maintained by buildingSMART International. buildingSMART International is actively facilitating IFC implementation and adaptation via local chapters worldwide.

Graphisoft, a CAD vendor and the developers of ArchiCAD, was the first software company worldwide to allow users to save/export their files in the IFC format.

IFC/ifcXML Specifications [edit]

- ifcXML2x3 (June 2007)
- IFC2x3 (February 2006)
- ifcXML2 for IFC2x2 add1 (RC2)
- IFC2x2 Addendum 1 (July 2004)
- ifcXML2 for IFC2x2 (RC1)
- IFC 2x2
- IFC 2x Addendum 1
- ifcXML1 for IFC2x and IFC2x Addendum 1



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Mila Kennett

Milagros Kennett is a senior program manager in the Infrastructure/Geophysical Division (IGD) of the Science & Technology Directorate, U.S. Department of Homeland Security. Currently, she manages several projects of the DHS S&T Counter IED Research Program and is responsible for the all IGD International Programs and activities. She is also in charge of a number of workshops to position the vision and goals for the division to support infrastructure resiliency and the infrastructure of the future with underlying principles of national continuity, energy, environmental sustainability, and resiliency. Ms. Kennett has more than 15 years of experience on projects in the Middle East, Asia, Latin America, Europe, and the United States. Her main focus has been on natural and manmade disaster mitigation; building security; risk assessments; and urban development. She was formerly Deputy Director of the Ministry of Public Works in the Dominican Republic and served as Dean of the School of Architecture and Engineering at the Centro de Estudios Tecnológicos. Ms. Kennett has been awarded and conducted large research projects for the U.S. National Science Foundation. She was the staff Architect of the Mitigation Branch of FEMA/Department of Homeland Security. She created and managed the Risk Management Series, which are a series of publications devoted to natural and manmade disasters. The Risk Management Series publications are intended to minimize conflicts that may arise from a multihazard design approach and to develop multihazard risk assessments methodologies for buildings exposed to chemical, biological, radiological, and explosive attacks as well as to earthquakes, floods, and high-winds. Ms. Kennett received a degree in architecture and urban design from the Universidad Autonóma de Santo Domingo and a master of arts degree in international development with a major in urban economics from American University in Washington, D.C.

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Tom Coleman

Thomas Coleman is the Infrastructure Protection Product Lead for the Transportation Security Laboratory (TSL), which is a Federal Laboratory assigned to the Headquarters of the Science & Technology Directorate, U.S. Department of Homeland Security. Mr. Coleman oversees research, testing, and product development in the areas of blast protection and durable building materials. Prior to assignment to TSL, he was a Director of Operations Research for Battelle, Managing Director for EGG Professional Services, and an active duty Air Force officer with field experience securing Departments of State and Defense installations in Europe. He holds a bachelor's degree from the State University of New York, Stony Brook, a master of science from University of Southern California, and is a graduate of the Air War College. He is a retired Lieutenant Colonel, U.S. Air Force Reserve.

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Alice Clark

Dr. Alice Clark currently serves as Vice Chancellor for Research and Sponsored Programs at The University of Mississippi. As the institution's chief research officer, she oversees the Office of Research and Sponsored Programs, which is responsible for facilitating and coordinating the acquisition and administration of fiscal resources and the development of infrastructure for conducting research and scholarly activities. In this capacity, Dr. Clark is the University's chief liaison with Federal offices.

She holds a faculty appointment in the School of Pharmacy, and in 1993 was named a Frederick A.P. Barnard Distinguished Professor of Pharmacognosy for her research efforts in discovering and developing pharmaceuticals from natural sources. She has published extensively on the discovery of novel biologically active natural products and the development of natural products as pharmaceuticals. As principal investigator she has received continuous NIH funding since 1984 to conduct research related to the discovery and development of new drugs for opportunistic infections.

She was a charter member of NIH's AIDS and Related Research Experimental Therapeutics study section, serving as chair from 1995-1997. She was a charter member and the first chair of the NIH panel on Drug Discovery and Mechanisms of Antimicrobial Resistance (2004-2007), and is currently serving a second term on the panel.

In 1993, Dr. Clark was elected as a Fellow of the American Association of Pharmaceutical Scientists, a designation limited to the association's top pharmaceutical scientists. In 1996, she was named the Rho Chi National Lecturer, the top award presented by this national pharmaceutical honor society.

Dr. Clark received her B.S. in Microbiology (1973) from Troy State University and her M.S. (1976) and her Ph.D. (1978) in Pharmacognosy from The University of Mississippi.

She serves as Chair of the Mississippi Research Consortium. She is on the Board of Trustees of the Southern Universities Research Association. She also serves on the Board of Directors for the Mississippi-Alabama Sea Grant Consortium, and serves as one of three gubernatorial appointments to the Southern Technology Council of the Southern Growth Policies Board.

Alexander Cheng

Alexander H.-D. Cheng, Ph.D. is Dean of Engineering at the University of Mississippi. He obtained his B.S. degree from the National Taiwan University, M.S. from the University of Missouri—Columbia, and Ph.D. from Cornell University, all in Civil Engineering. He was a faculty member at Cornell University, Columbia University, and the University of Delaware, before he joined the University of Mississippi in 2001 as Chair of Civil Engineering Department, and became Dean in 2009.

His research interests include nanomechanics, meshless method, poromechanics, and groundwater flow. He is the co-editor of the journal Engineering Analysis with Boundary Elements, and was an associate editor for the Journal of Engineering Mechanics, ASCE. He is also the editor-in-chief of the book series Progress in Water Resources, WIT Press. He has authored three books, and edited four specialty books, plus seven conference proceedings. He has published more than 100 journal papers. He was the co-founder of two conference series: the Biot Conference on Poromechanics, and the International Conference on Saltwater Intrusion and Coastal Aquifers. He was the recipient of the Walter L. Huber Civil Engineering Research Prize from ASCE, and the Basic Research Award from the U.S. National Committee for Rock Mechanics, National Research Council. He currently serves as the Vice President of Engineering Mechanics Institute, American Society of Civil Engineers. He was formerly the Vice President for Academic Affairs of the American Institute of Hydrology. He is also on the Board of Directors of the Wessex Institute of Technology. His recent research projects include two with the Department of Homeland Security, and one with Office of Naval Research, on blast protection of critical infrastructure using nano-particle-reinforced composites, and on blast and impact protection of navy ships.

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Mohammed Ettouney

A biography of Dr. Ettouney can be found on page 10.

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Eric Letvin

A biography of Mr. Letvin can be found on page 5.

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ORGANIZERS

BIOGRAPHIES

Ahmed Al-Ostaz

Dr. Ahmed Al-Ostaz is an Associate Professor of Civil Engineering at the University of Mississippi (Ole Miss). Before joining Ole Miss in 2002, Dr. Al-Ostaz was a Visiting Assistant Professor at Composite Materials and Structures Center and an Adjunct Assistant Professor in the Department of Materials Science and Mechanics at Michigan State University. He focuses his research on utilizing advanced materials (nano-enhanced, bio-inspired and self-healing materials) in structural applications using multi-scale experimental and numerical tools. He published more than 50 journal and conference papers. Dr. Al-Ostaz has been the PI and Co-PI on research projects funded by Office of Naval Research, Department of Home Land Security, Air Force Lab (AFL), NASA EPSCoR, Mississippi Space Consortium, Michigan Department of Transportation, Mississippi Department of Transportation, General Motors Company, Research of Excellence Funds (State of Michigan) and NSF-SBIR program with a total funding of more than $5 million. Currently he is a Co-PI in two major research projects sponsored by the Department of Homeland Security Science and Technology Directorate (DHS S&T) through the Southeast Region Research Initiative (SERRI) administered by Oak Ridge National Laboratory, and one project funded by Office of Naval Research. He was selected by faculty, students and the engineering alumni of the school of engineering at the University of Mississippi as the Outstanding Engineering Faculty Member of the Year during the academic year 2005-2006.

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Chris Mullen

Chris L. Mullen, Ph.D. is Associate Professor of Civil Engineering and a newly appointed interim chair of the Department of Civil Engineering at the University of Mississippi. Dr. Mullen received his Ph.D. from Princeton University in 1996 and then joined the faculty at The University of Mississippi. After receiving his MSCE from Rice University in 1981, he spent 5 years with Mobil R&D, 2 years with ADAPCO, and 3 years at Weidlinger Associates. He has taught a variety of courses in the area of Mechanics, Structures, and Design. He has expanded a strong research program in the area of Structural Mechanics and Earthquake Engineering and now serves as Associate Editor of the ASCE/SEI Journal of Structural Engineering in the area of Methods of Analysis. Since 2002, he has served as founding director of the UM Center for Community Earthquake Preparedness and been PI on a number of hazard mitigation planning research projects sponsored by MEMA, FEMA, and others. During Hurricane Katrina he served in MEMA's EOC and as the MS representative for the subsequent FEMA Mitigation Assessment Team. He is now a co-PI on a major blast resistant structures research project sponsored by the Department of Homeland Security Science and Technology Directorate (DHS S&T) through SERRI administered by Oak Ridge National Laboratory. The project has enabled collaboration with two national laboratories: 1) Geotechnical and Structures Laboratory at the U.S. Army Engineer Research and Development Center in Vicksburg, Mississippi, and 2) Building Fire Research Laboratory at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland.

Introduction

At the end of each day, the participants split into breakaway sessions to share ideas and discuss the technologies and strategies introduced in the presentation sessions. These breakaway sessions helped develop the direction of the DHS S&T stabilization research committees. Each breakaway group used a “Breakaway Session Matrix” to generate valuable and directed conversation on the day’s topics. In addition to asking pointed questions, the matrix is set up with suggested discussion items across the top and down the left side of the page. The intention is not to fill out a grid, but rather to cross the ideas in the top row and left column to generate ideas. The matrix and key discussion points are provided below.

BREAKAWAY SESSIONS

DISCUSSION POINTS

DAY 1: METHODS AND TECHNIQUES

Breakaway Session 1A: Sensors

Sensors	Types of suitable sensors for near-collapse buildings	Acoustic, optical (laser), electro-magnetic, infrared thermography, other	Power supply requirements	Size and weight requirements. Ruggedization requirements.	Accuracy of measurements. Acceptable tolerances.	Differences between before and after event sensing	Other
Wireless sensing technologies	What kinds of sensors are suitable for use before, during, and after an IED attack that leads to building instability? What is the role of remote sensing? What is the role of wireless sensors? How should sensors be used before an event in new / existing buildings? What is the current state of technology of these sensors?						
Remote sensing technologies							
Sensor networks in buildings							
Special needs of near-collapse buildings							
Use in pristine structures							
Other							

Discussion

What kinds of sensors are suitable for use before, during, and after an IED attack that leads to building instability?

- Before an IED attack:
  - More research is needed to determine the need for baseline pre-event verses post-event
  - The structure changes after an event, therefore changing the baseline
- During an IED attack:
  - The sensor should indicate peak yield estimate (pressure/strain)
- After an IED attack:
  - There needs to be a way to assess the situation without a baseline
  - The sensor should monitor p-delta movement to look for progression of strain (no need for baseline)
- It is not practical to establish a baseline for every building, but we can prioritize by establishing baselines for critical buildings
- Types of sensors: thermography (during event), strain, accelerometers, crack growth monitor (before and after), laser, and optical (Shadow Moiré)
- 3-D Laser Position System/High Rise Digital System:
  - Tracks movement
  - Assesses how much the new baseline changes
  - Expensive to implement but reusable
- During/after sensors are more useful to first responders but useful to have data before attack for owners and insurance

What is the role of remote sensing?

- Remote sensing provides 3D imaging of what is occurring in a building
- Can help first responders determine whether it is safe to go in or not

What is the role of wireless sensors?

- Wireless sensors help us understand the changes in parameters at the micro level
- This is especially helpful in detecting or predicting brittle failure

How should sensors be used before an event in new/existing buildings?

- To classify structures in general in order to identify parameters: start from FEMA classifications, select those that are more appropriate for blast.
- To link BIM to structural health monitoring (SEI has started this effort)
- To prioritize by critical factor(s)
- Other things to consider:
  - Do we want an instrument for blast only, or for other hazards? Incentive to accommodate more than one hazard.
  - What is likelihood of sustainability between sensors, data, and buildings?

BREAKAWAY SESSIONS

DISCUSSION POINTS

What is the current state of technology of these sensors?

- Sensors need to be compatible with new technology
- Sensors need to be designed for longevity
- Sensors need to be accessible

Based on our discussion and your experience, specify adequate types of sensors that should be used before and after a building is attacked by an IED.

Before an attack	After an attack
• Sensor technology that indicates progressive change • Sensors used before an attack can be useful for insurance • Need Information to categorize behaviors of building	• Depends on the type of threat • Motion sensors, anchrometers, and tiltometers • Mobile (and expensive) sensors • Rapid screening tools • Need to define thresholds to aid first responder decisions

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Breakaway Session 1B: Needed Information

Needed Information	Before attack: structural properties, structural baseline behavior	Before attack: location and type of sensors (if any); sensor measurements (as a baseline)	Crack sizes and growth, condition of connections, large deflections, stability of walls	Debris mechanics and stability. Unusually heavy weight on floors or beams.	General conditions of different components as well as the whole structural system	Lateral structural systems: steel bracing or concrete shear walls	Other
Information relayed in real time							
Information is used to ascertain potential structural instability							
Local collapse as opposed to global collapse							
Vulnerability of building envelope to collapse							
Nonstructural components							
Unreinforced masonry or brick walls							
Older vs. newer construction							
Type of building envelope (glass curtain walls, masonry, concrete units, etc.)							

What information do first responders need regarding a near-collapse building before, during, and after an IED attack?

Would information about pristine buildings be of value? Why?

How would sensor measurements be used to provide such information?

What are the efficient methods of displaying such information?

What is the state of current information technologies?

Discussion

What information do first responders need regarding a near-collapse building before, during, and after an IED attack?

- Information needs and availability depend on the age of the building
    - Structural health monitoring information is useful
- First responders need a framework of information (e.g., construction type, configuration)
    - This information should be correlated to the Risk Assessment/Analytics tool so that the tool can pre-populate the first responder assessment tool
- Level of detail provided depends on whether it is for first responder (police, fire) or advanced responder (structural specialist)
- The monitoring and sensing tools should convey the following to aid first responders:
    - Is change occurring?
    - What is changing?
    - How fast is it changing?
    - What are the warning signs before failure?
    - Can we measure the changes in stiffness? For example, seeing the frequency of vibration increase in the World Trade Center columns.

Would information about pristine buildings be of value? Why?

- Establishing a structural baseline requires long-term sensing of a specific building. This is a huge undertaking when performed on multiple buildings.
- It makes sense to establish a baseline for iconic or high-volume buildings that are most likely to be attacked, or if attacked would have a high number of casualties. Otherwise, it is not cost-effective and only post sensors should be used.
- Buildings are currently classified by collapse potential/collapse pattern.

How would sensor measurements be used to provide such information?

- Sensors can survive blast/fire relatively well
- Pre-deployed sensors are often programmed to send information intermittently to save on cost. There is no guarantee that they will be sending information at the time of the event.
- Pre-deployed acoustic sensors are not useful
- Pre-deployed tensile and tilt sensors can provide baseline and change from baseline
- Post-deployed acoustic sensors can detect micro fractures of overloaded members
- Could have post-deployed sensors deployed by firefighters to start trending data as soon as possible

What are the efficient methods of displaying such information?

- Provide first responders with a way to determine safety: red, yellow, green seems to work
- There is concern for data overload

What is the state of current information technologies?

- Digital imaging is available but there is data overload by taking an image every second and comparing the change
- Fusion of visible and thermal cameras to compare second-to-second streaming information
- Electromagnetic imaging can help us see through concrete and walls and see movement in the structure. Users can see a few meters behind the walls they are trying to sense.
- Remote sensing and signal extraction are not too advanced yet
- Technologies to research:
    - We should test survivability of sensors in explosive events
    - We should use existing incidents to predict damage patterns for old and new building types. This could help predict locations of voids.
    - We should look into what is already being done with high value asset buildings that have been sensors. Do they already have analysis models?

Based on our discussion and your experience, what do you believe are the most important types of information that sensors can provide regarding IED-attacked buildings?

Pristine Buildings	Near-Collapse Buildings
• Disseminate current information to first responders • Create framework for first responders to gather information from their local jurisdiction that can be input into risk assessment tool that is being developed • Need BOTH pre- and post-explosion monitoring (pre for more iconic, important buildings) • For building types not being monitored, provide additional first responder training	• Change (warning of imminent failure) • Location of change (which elements have changed)

BREAKAWAY SESSIONS

DISCUSSION POINTS

Breakaway Session 1C: Structural and Damage Identification

Structural and Damage Identification	Modal and parameter identification, high-frequency structural identification methods	Non-destructive testing techniques, laser measurements	Strain, velocity, and displacement measurements and how they relate to damage identification	Sensor networks. Sensor triangulation. Large sensor arrays.	Changes in structural properties as they near collapse (stiffness, frequency, etc.)	Real-time and near-real-time damage detection	Other
Develop structural models that are up to date. Relate such models to sensor measurements using parameter updating methods.							
Relate measurements after IED attack to probable damage in structure							
Estimate severity of damage as measured							
Estimate potential of structural or component instability							
Relay damage information in a simple, speedy, and logical manner							

What structural identification techniques can be of use?

What damage identification techniques can be of use?

What different damage types are of interest?

How efficient are current sensors in detecting is damage? Can such detection be done in real time?

How would damage identification methods relay damage information to first responders?

Discussion

What structural identification techniques can be of use?

- Rapid Visual Screening publications that assess buildings based on characteristics
- ERDC worldwide structures database that categorizes buildings in different countries

What damage identification techniques can be of use?

- StS manuals that describe failure mode by structure types, based on ATC Rapid Visual Screening for Earthquakes

What different damage types are of interest?

- How the structure came down, in order to locate possible void spaces
- Quality of construction, in order to gauge potential future collapse
- Strength and stability of partially damaged buildings
- Level of damage to critical elements
- Detecting stability is more important than detecting damage

How efficient are current sensors in detecting damage? Can such detection be done in real time?

- Current state of the art sensors detect whether the whole system has changed, which has its limits for predicting collapse
- Current sensors have no way of getting down to details of specific elements
- There are a lot of variables, such as wind and sunlight, that need to be filtered out to make sensors more accurate
- Significant time needed to establish baseline; valuable for critical facilities but not cost-effective for regular commercial buildings that might be in vicinity of target building

How would damage identification methods relay damage information to first responders?

- Information to the micron might not be useful to first responder
- Probabilistic approach to aiding the go/no-go decision, should not have just one hard threshold
- Simplify data to make educated decisions (Red/yellow/green approach)
- Combine expertise of all fields
- Understand objectives of first responders and engineers

BREAKAWAY SESSIONS

DISCUSSION POINTS

Based on our discussion and your experience, what are the two most important types of damage and how are they relayed to first responders?

Types of Damage	How Relayed to First Responders
• Partially collapsed structures – we need monitoring to make sure remaining structure is not going to collapse on responders • Different failure mechanisms – ductile, brittle, instability	• 3D BIM modeling of building plans to assess structural elements, possibly identify voids, determine where sensors could be placed • Different sets of user interfaces for different responders to relay information to the level of detail needed (short-term and long-term) • Educate firefighters in structural basics, encourage hiring engineers on staff at fire station to close knowledge gap

DAY 2: NEEDS AND SOLUTIONS

Breakaway Session 2A: Real-Time and Near-Real-Time Decision Making

Real-Time and Near-Real-Time Decision Making	Search and rescue, engineers, architects, firefighters, police, owners, officials, etc.	Role of statistics and probabilities in decision making	Relating engineering information to useful real-time decisions	Role of experiments, experience, analysis, and observations in providing guidance to decision-making processes	Balancing hazards, vulnerabilities and consequences in decision making	Prioritization of actions based on information available to stakeholders	other
Warning of structural movement in failure mode of concern	Who are the stakeholders that need to make decisions after an IED attack? What are the decisions that are needed to be made by different stakeholders? How would information gathered by sensors be translated into decision by first responders and other stakeholders? What are different decision-making techniques? How beneficial is using probabilistic techniques to make decisions?						
Warning of debris or other localized movement							
Warning of shoring stabilization loss							
Adaptable to specific building near-collapse situation							
Permit distinguishing benign from non-benign structural movement							
Acceptable cost and false alarm risk							

Discussion

Who are the stakeholders that need to make decisions after an IED attack?

- First Responders – police department, fire department, city engineers
- Other Stakeholders – utility companies, forensics, general public, Department of Environmental Quality
- Mutual Aid and head of emergency operations at the State level to call for different resources around the State
- Emergency directors of mass notification systems

What are the decisions that are needed to be made by different stakeholders?

- To evacuate or not evacuate?
- Is it safe to enter? We need to define threshold or indicators on sensor data
- Police/Fire – Can we handle this ourselves? Do we need more resources?
- What equipment is appropriate and usable for the present hazards? Do we need major equipment (cranes, front-end loaders)?
- Resolving of conflicting information
- Collapse/Evacuation Zone, egress protocols
- Do we initiate the Incident Command System (ICS)?
- Is this an isolated event, or widespread or multiple attack scheme?
- Prioritization of different areas of damage
- HAZMAT personnel need to look for secondary devices/hazards
- Prioritization of victims
- Consequences of partial collapse

How would information gathered by sensors be translated into decision by first responders and other stakeholders?

- Green, Yellow, Red for different areas of the building – Make a software where observations are the input, and the computer makes a quick interpretation and decides
- Graphical presentations of data to simplify complex data

What are different decision-making techniques? How beneficial is using probabilistic techniques to make decisions?

- Probability is the most common decision-making technique
- It can be difficult to determine a threshold with a probabilistic technique, and people get too tied up with numbers

Based on our discussion and your experience, what are the most important decisions that can be provided to first responders immediately after an event and 24 hours after an event?

Immediately	24 Hours After
• Where can the search team start working? Give absolute positives first. Safe access and safe exits. • Where is the best location to rescue people? • Has the structure momentarily come to rest? • How to contain the event?	• What is the best path to save lives? • What are the movements of the structure? • How do we best shore up and retrofit the building? • What is the mitigation plan? • What are the first responders' capabilities?

BREAKAWAY SESSIONS

DISCUSSION POINTS

Breakaway Session 2B: Knowledge Gaps and Future Challenges

Knowledge Gaps and Future Challenges	Sensor technologies, non-destructive testing techniques	Structural stability signs, cracking, deflections	Damage identification methods	Remote sensing, wireless sensing, sensor networks	Behavior of structures and nonstructural systems after an IED attack	Debris mechanics and analysis	Cost of technology, cost of research, cost of training; technology transfer
Vendors / Industry	What type of sensors are needed? What advances in damage detection methodologies are needed? What decision-making techniques are needed to improve stakeholders efficiencies? What research efforts can help the above needs? What are the benefits and challenges to using Building Information Modeling (BIM) to provide better information to stakeholders? In terms of improving sensing of near-collapse buildings, what are the benefits of deploying high-performance buildings? What are the challenges?						
Federal / State / Local							
National Labs / Research Institutes							
Professional Organizations							
Universities							
Other							

Discussion

What types of sensors are needed?

- Acoustic sensors
- GIS-type sensors to detect voids

What advances in damage detection methodologies are needed?

- Assess structural integrity
- Produce data with enough time to provide warning to responders
- Sense brittle failure
- Sense pre-damage baseline
- Sense at the micro-level to predict macro-level behavior
- Find voids in debris piles

What decision-making techniques are needed to improve stakeholders' efficiencies?

- Guidelines on risks of failure of different building types and attributes to consider
- Decision-making without providing numbers
- A way to process data. The data is available but what do we do with it once it is collected?
- Determination of threshold
- Using BIM to determine where sensors should be placed

What research efforts can help the above needs?

- Develop a wireless monitoring system implemented in the field
- Perform a demonstration of cluster RFIDs
- Basic acoustic sensing research
- Decision-making needs of first responders
- Research to determine threshold
- Create a BIM standard for first responders that can be applied to every building
- BIM demonstration project using Murrah Building as case study

What are the benefits and challenges to using Building Information Modeling (BIM) to provide better information to stakeholders? How does BIM tie into sensor needs?

- BIM is the end product; we need to have the data to put into BIM
- It is beneficial to have data for buildings surrounding the critical facility being monitored because they are subject to collateral damage and can create more debris
- It takes time to data mine BIM model
- We could take damaged elements out of BIM model and see how the building reacts

DISCUSSION POINTS

In terms of improving sensing of near-collapse buildings, what are the benefits of deploying high-performance buildings? What are the challenges?

- Benefits
  - Determine where to place sensors to maximize valuable data
  - Determine location of possible voids
- Challenges
  - Convincing stakeholders to use BIM

Based on our discussion and your experience, what are the most important knowledge gaps that need to be considered, both in the short term and the long term?

Short-term	Long-term
• Develop and demonstrate a wireless system • Correlate sensor output to damage detection and collapse prediction, and compare to healthy buildings • Has the structure momentarily come to rest? • Apply sensors to field tests already being done at ERDC	• Identify precursor parameters that indicate onset of brittle failure at both the structural and material level • Model damage information from past events