Advanced Instrumentation, Information, and Control Systems Technologies

Light Water Reactor Sustainability

Online Monitoring of Material Aging and Degradation in Nuclear Power Plants

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Light Water Reactor Sustainability R&D Program

Research Team

- Research Funded under the Advanced Instrumentation, Information, and Control Technologies Pathway
- Idaho National Laboratory – Lead Institute
  - Vivek Agarwal and Andrei V. Gribok
- Vanderbilt University – Lead University Partner
  - Profs. Sankaran Mahadevan and Douglas Adam
- University of Alabama Tuscaloosa
  - Prof. Eric Giannini
- Oak Ridge National Laboratory and University of Tennessee Knoxville – Activities funded by the Material Aging and Degradation Pathway
  - Yann LePape, Dwight Clayton, and Prof. Ma

LWRS
Light Water Reactor Sustainability

Project Overview

- Online monitoring of passive structures
  - Concrete structures
  - Secondary system pipes

- Support long-term and reliable operation of current fleet of the U.S light water reactors

- Develop a structural health monitoring (SHM) framework that can be extended to other material aging and degradation

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Courtesy: NRC and MISTRAS Inc.

Present Challenges

- Age-related deterioration of plant structures
  - Physical, chemical, mechanical and radiological degradation
  - For example, alkali-silica reaction (ASR) in concrete structures and corrosion in piping systems

- Lack of advanced technology solutions
  - Periodic visual inspection
  - Localized non-destructive evaluation

- High operational and maintenance cost due to scheduled or unscheduled downtime
  - To remain competitive in energy market
  - Increase operational efficiency and productivity

- Current SHM in the nuclear industry is strictly NOT ONLINE

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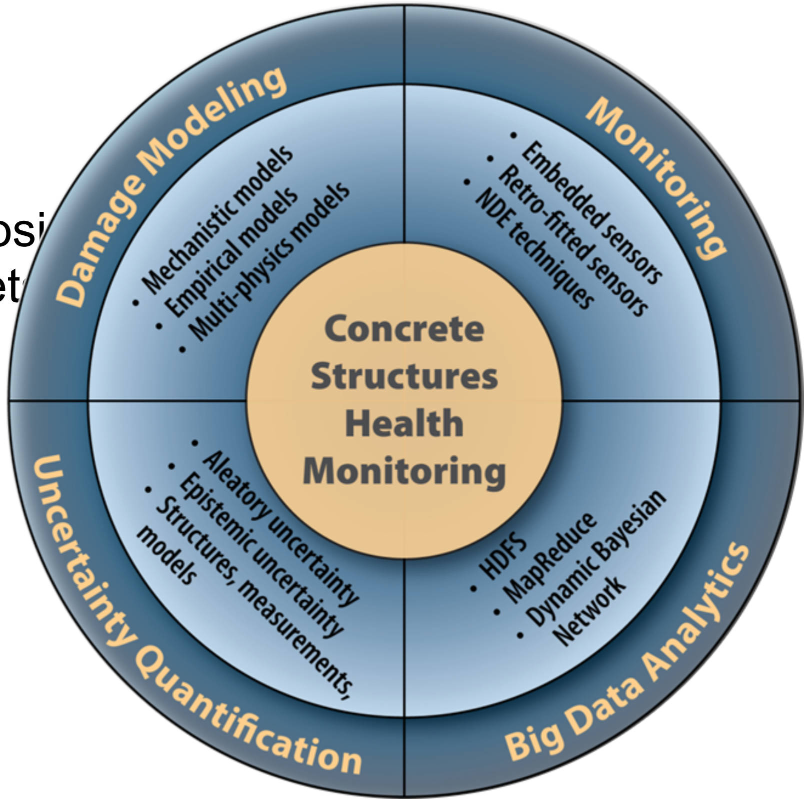
Concrete SHM Framework

Monitoring
- A variety of NDE techniques can be used
- Full-field techniques investigated: thermal imaging, digital image correlation (DIC)
- Vibration-based techniques

Data analytics
- Process the raw monitoring data for diagnosi
- Consider heterogeneous and large data set

Uncertainty quantification
- Integrate all available information and facilitate risk quantification

Damage modeling
- Leverage existing modeling efforts
- Use diagnosis result for prognosis



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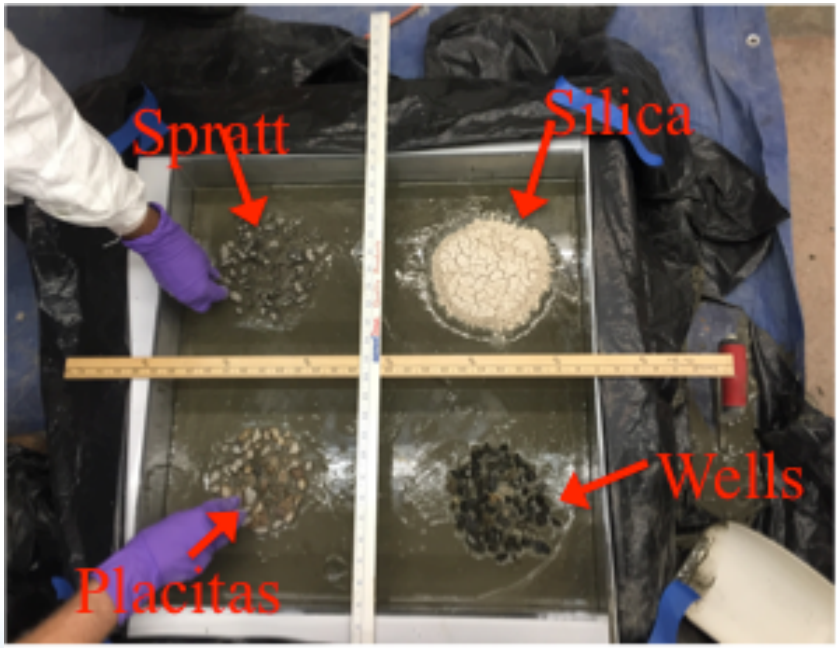
Concrete Samples

- Three 9- x 5- x 2-in. concrete samples
  - Glass and various aggregates
  - Baseline sample cured in water
  - Reactive sample cured in NaOH

- Large concrete sample 2 ft x 2 ft x 6 in.

Forklift placing slab in the oven

Pouring the cement into the mold



Pockets of aggregate with labels

Vibro-Acoustic Modulation (VAM)

- Low-frequency "pumping" signal and high-frequency "probing" signal
- A nonlinear system can be identified by interactions between the two inputs, or the system's linear response to each individual input

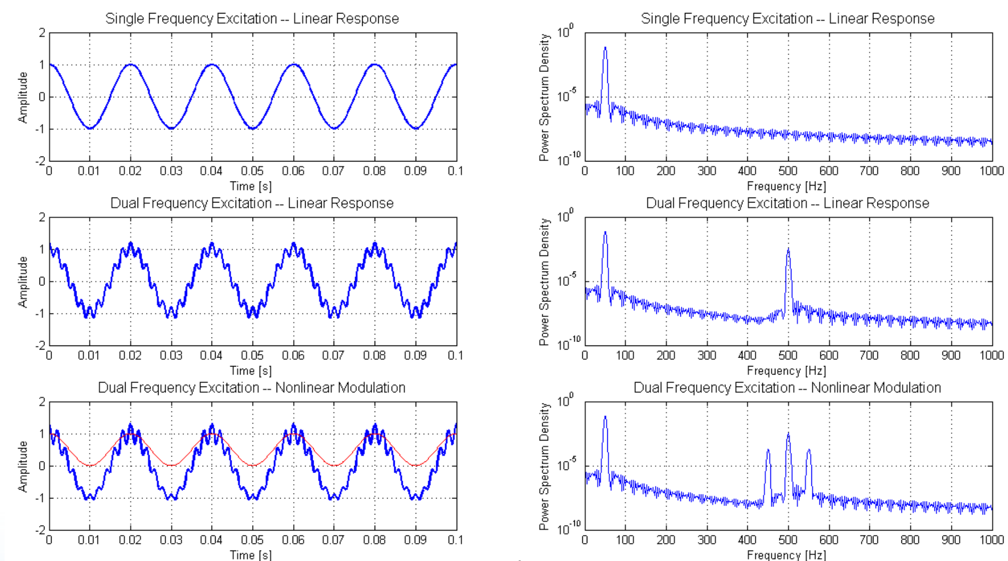
*Modulation is specifically a product of responses that manifests in the frequency domain as a convolution of spectra

$$\cos(\omega_1 t)$$

$$\cos(\omega_1 t) + \cos(\omega_2 t)$$

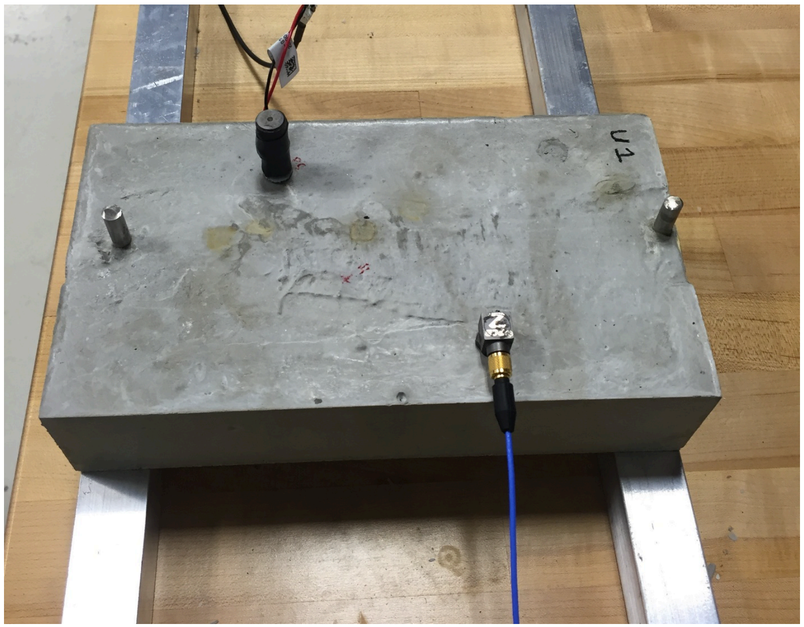
*Modulation term

$$\cos(\omega_1 t) + \cos(\omega_2 t) + \cos(\omega_1 t)\cos(\omega_2 t)$$

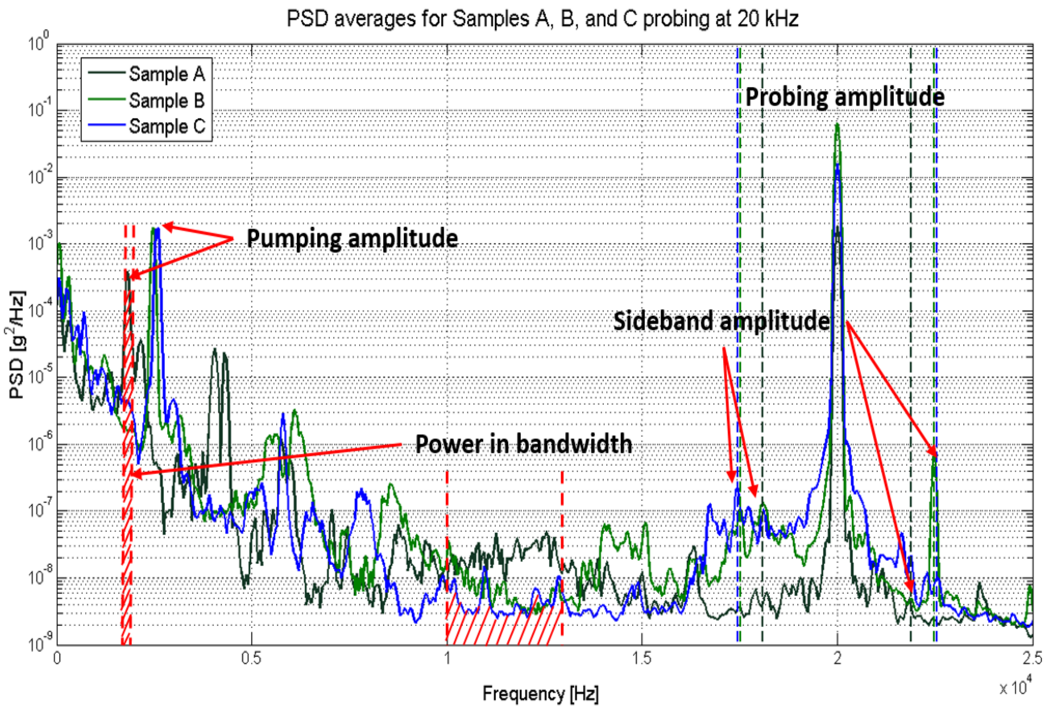


Notional Figure

Vibro-Acoustic Modulation - Result

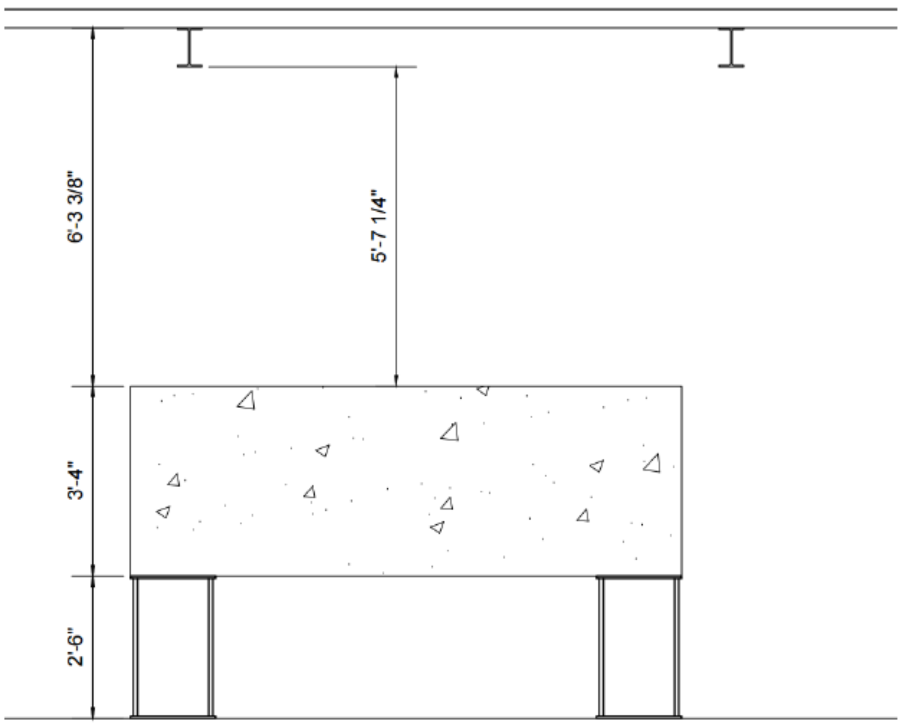


VAM Experimental Set-up



VAM Spectrum on 3 concrete samples

Digital Image Correlation (DIC) Set-Up at UTK



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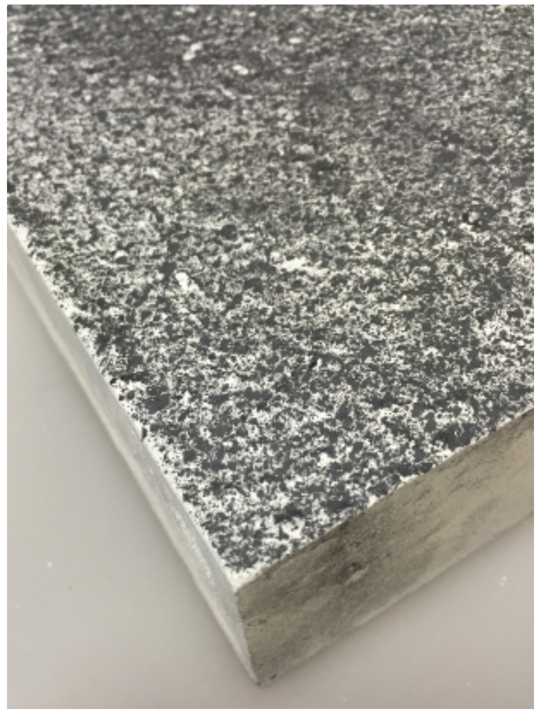
Digital Image Correlation (DIC) Set-Up at UTK

- Speckle patterns and durability test of paint under high relative humidity of the environmental chamber

Oil-based paint

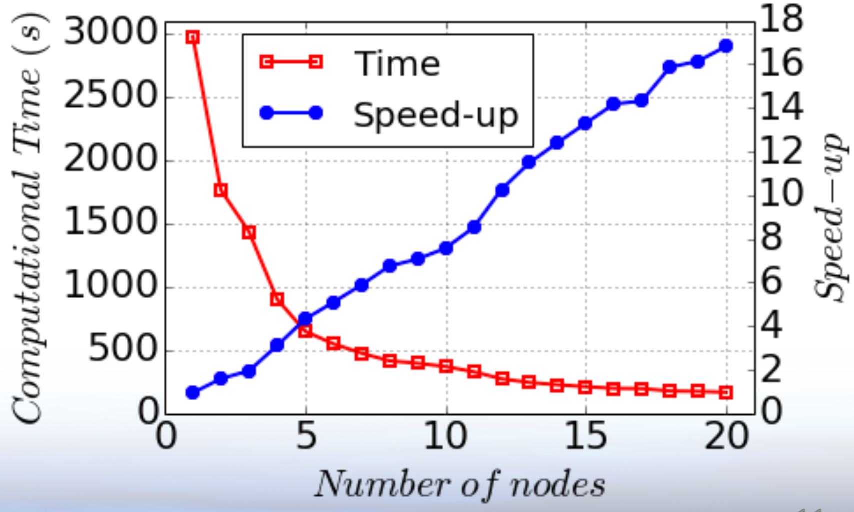


Acrylic latex

Speckle patterns on UTK sample

Other Accomplishments

- Monitoring Techniques
  - Infrared thermography and Nonlinear Impact Resonance Acoustic Spectroscopy were performed on concrete samples
- Data Analytics
  - Heterogeneous large data set were processed and MapReduce was implemented
- Uncertainty quantification
  - Integrate all available information and facilitated uncertainty quantification



Technology Impact

- The framework is extendable to other passive structures
- Would enable online monitoring of aging passive structures to support long term sustainability of nuclear plants
- Introduce advance technology solutions
- Maintain economic competitiveness of the nuclear industry in the US energy market

Summary and Path Forward

- Different monitoring techniques were evaluated to study ASR degradation on concrete samples
- Vibro-acoustic modulation seems to provide insight on degradation due to ASR
- Digital image correlation instrumentation were installed at the large concrete sample at UTK
- Heterogeneous data were analyzed and MapReduce methodology was implemented
- Uncertainty quantification based on different available information was performed

Path Forward

- Further investigate application of VAM on concrete samples made of different reactive aggregates (provided Univ. of Alabama)
- Cross-verify VAM with chemical changes in the concrete mix using chemical sensors (for example, Strain and pH sensors)
- Continue to collaborate with ORNL and UTK to collect DIC data and study ASR degradation in large concrete samples
- Initiate work with University of Nebraska – Lincoln awarded under the Nuclear Energy University Program on concrete SHM
- Engage industry participation

Milestone Reports and Publications

- Two level 2 milestone reports were completed
- Cai, C., and Mahadevan, S. Big data analytics in online structural health monitoring. International J. of PHM, vol. 7, pages 11, 2016
- Mahadevan et al. Quantitative Diagnosis and Prognosis Framework for Concrete Degradation Due to Alkali-Silica Reaction. QNDE Conference, Atlanta, GA, July 2016.