# Vibration-Based Non-Destructive Evaluation of Concrete Structures

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August 2019

**INL**
Idaho National Laboratory

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**Idaho Falls, Idaho 83415**

**http://www.inl.gov**

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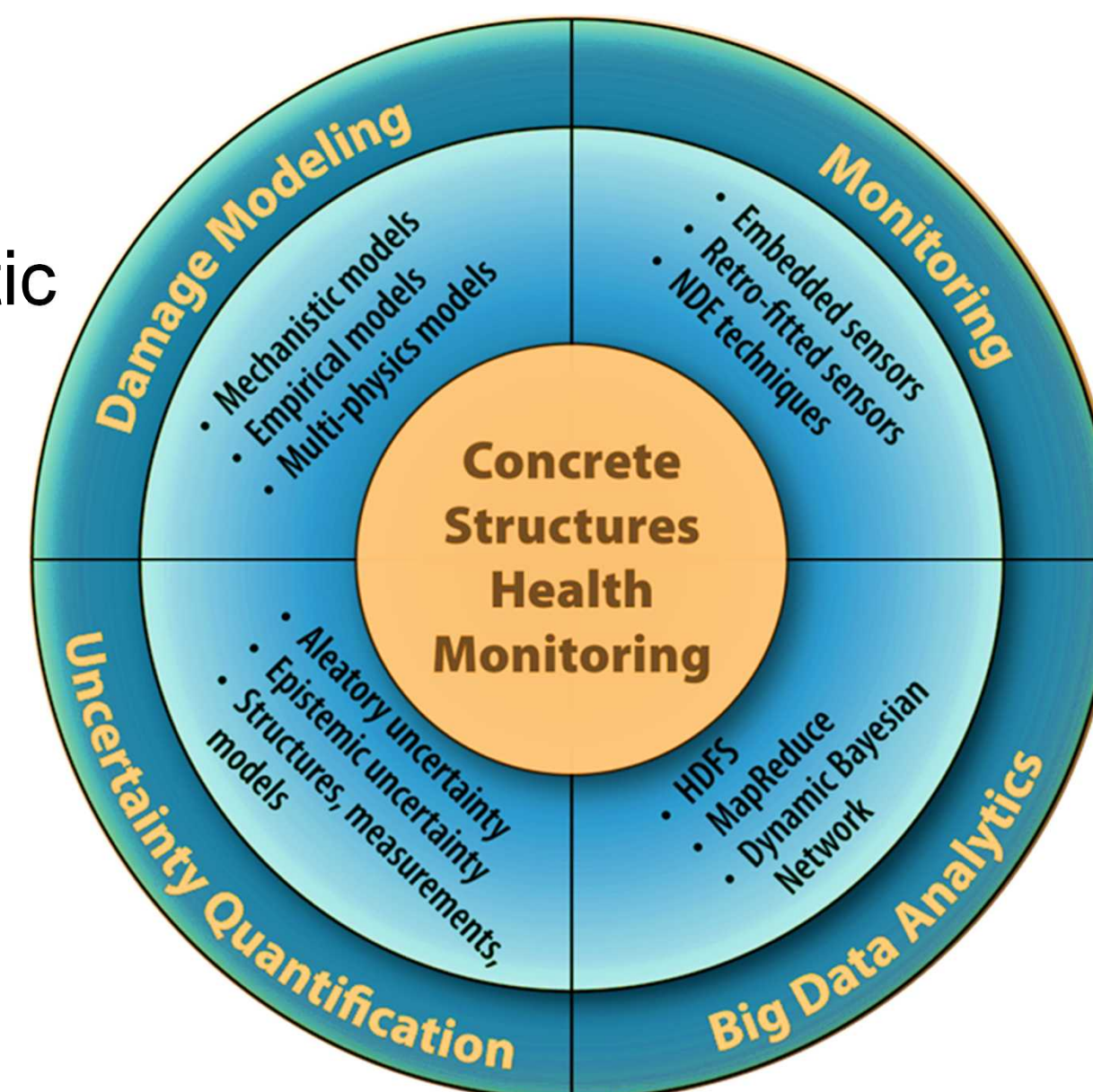LWRS LIGHT WATER REACTOR SUSTAINABILITY

# Vibration-Based Non-Destructive Evaluation of Concrete Structures

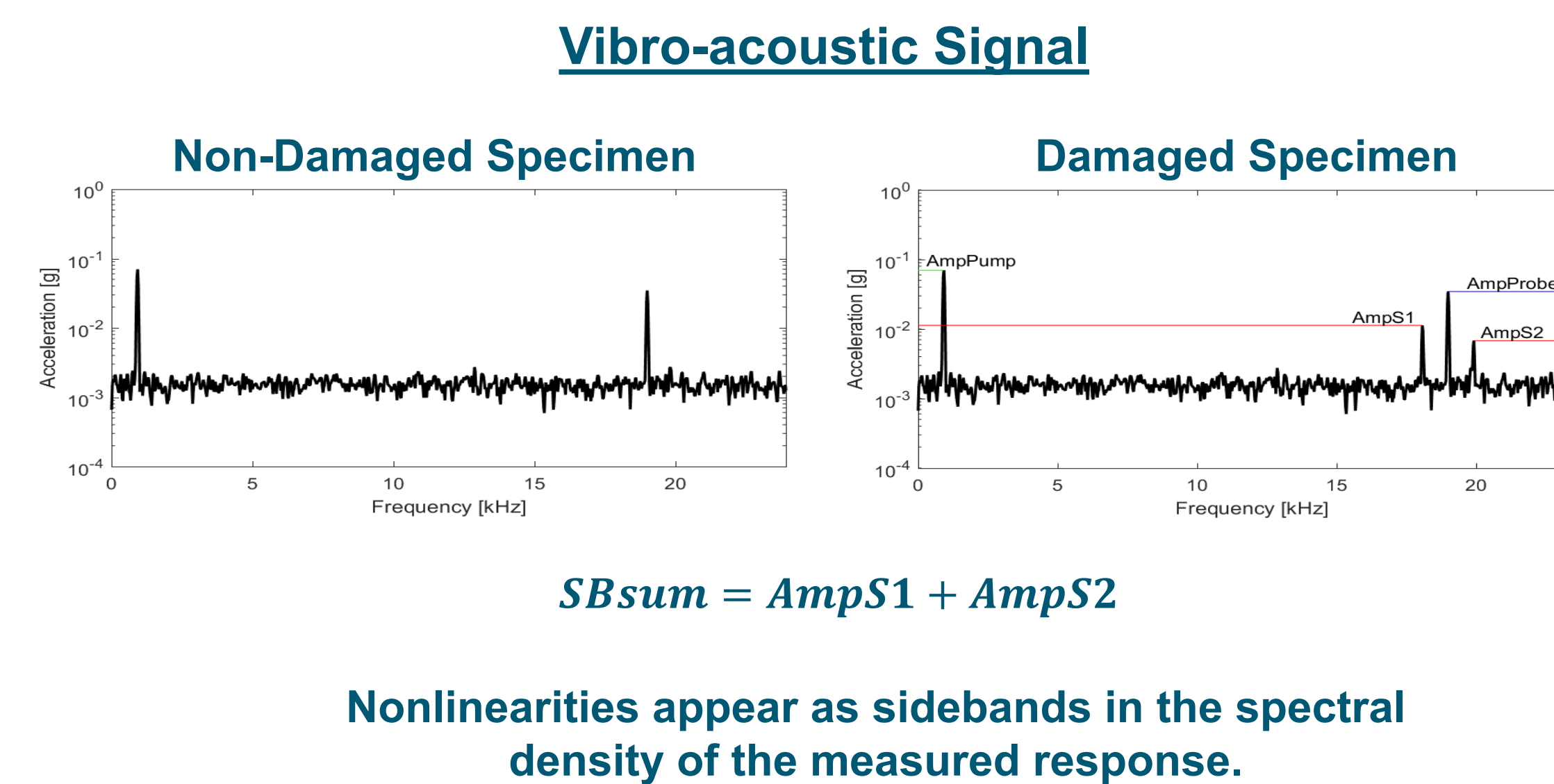Sarah Miele[1] and Vivek Agarwal[2]        [1]Vanderbilt University, Nashville, TN, [2]Idaho National Laboratory, Idaho Falls, ID

## Motivation

- **Objectives**
  - Health diagnosis and prognosis framework for concrete structures
  - Support long-term operation of domestic fleet of nuclear power plants
  - Focus on alkali-silica reaction (ASR)
- **Degradation Mechanism: ASR**
  - Chemical reaction
    - Highly alkaline cement paste
    - Reactive aggregate
  - Moisture → expansion of ASR gel



## Vibro-Acoustic Modulation (VAM)

**Vibro-acoustic Signal**

**Non-Damaged Specimen**    **Damaged Specimen**



$$SBsum = AmpS1 + AmpS2$$

**Nonlinearities appear as sidebands in the spectral density of the measured response.**

- **Basis**
  - ASR-induced cracks cause nonlinear structural behavior
  - Nonlinear structural response to a bi-harmonic excitation results in sidebands in the frequency domain
- **Applied Frequencies to the Structure**
  - Actuators were used to excite the specimen with the pumping and probing frequencies.
  - Sidebands clearly visible in spectral plots
- **Damage mapping**
  - The sums of AmpS1 and AmpS2 were calculated for each accelerometer
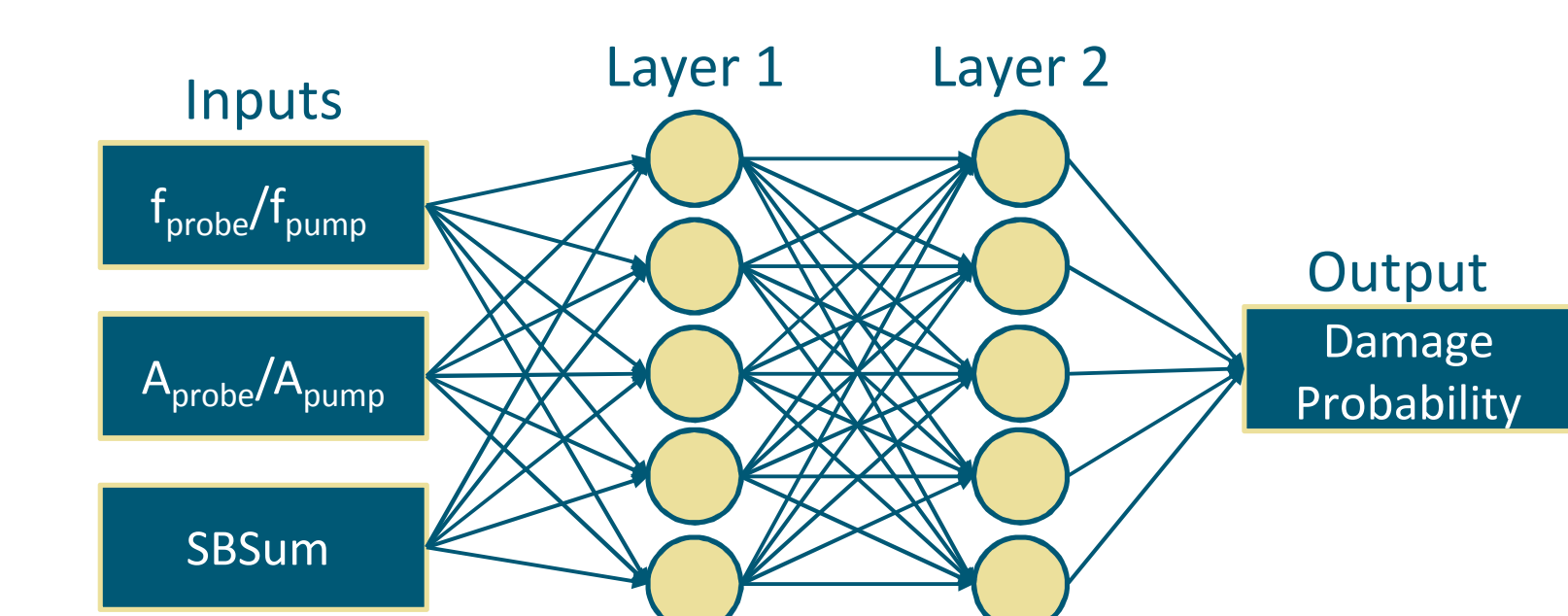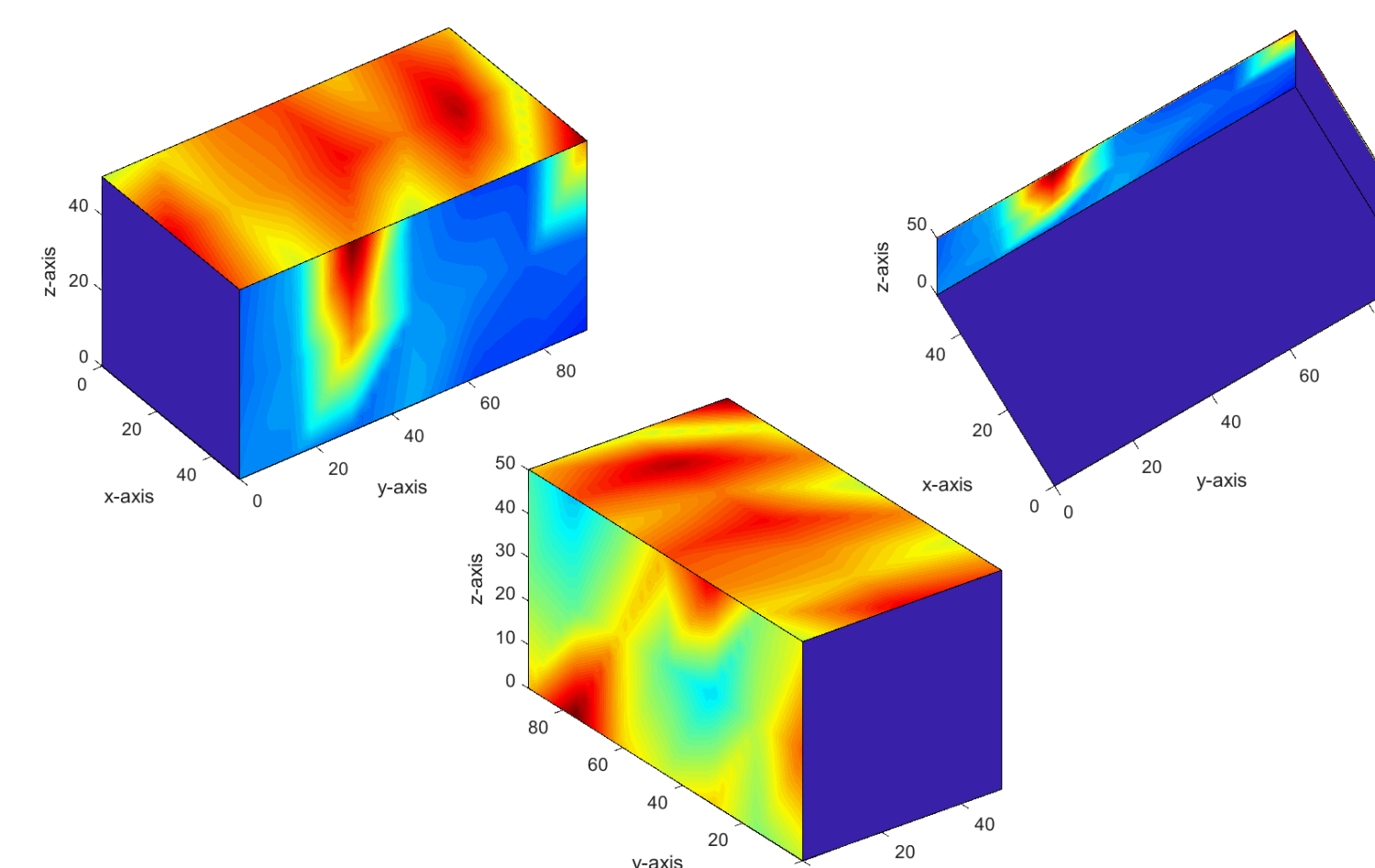
## Experimental Analysis

**Aggregate Locations**    **Vanderbilt Slab**    **Actuator Placement**    **1'x2'x1' Specimens**
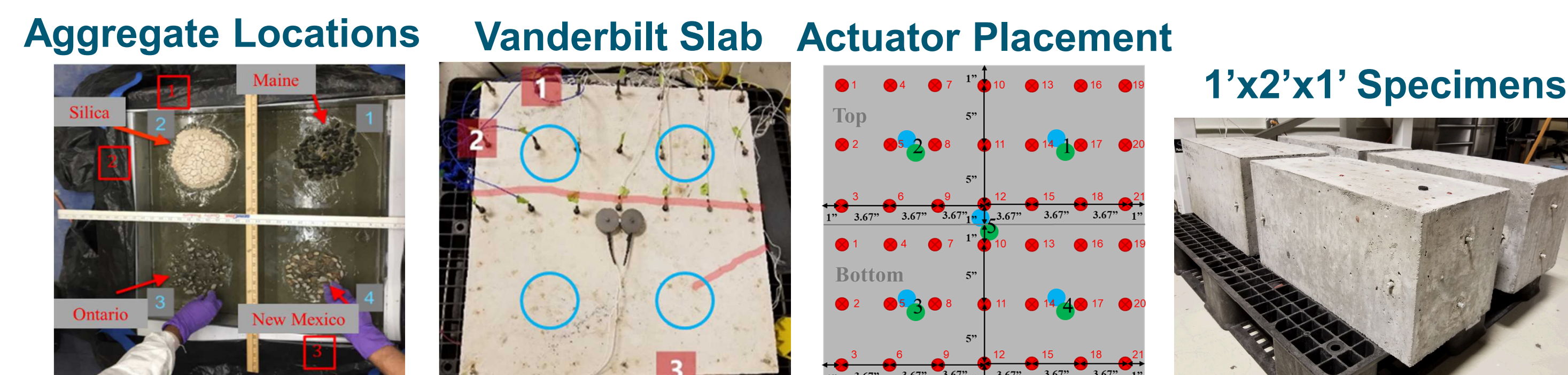


### Description of Specimens Tested

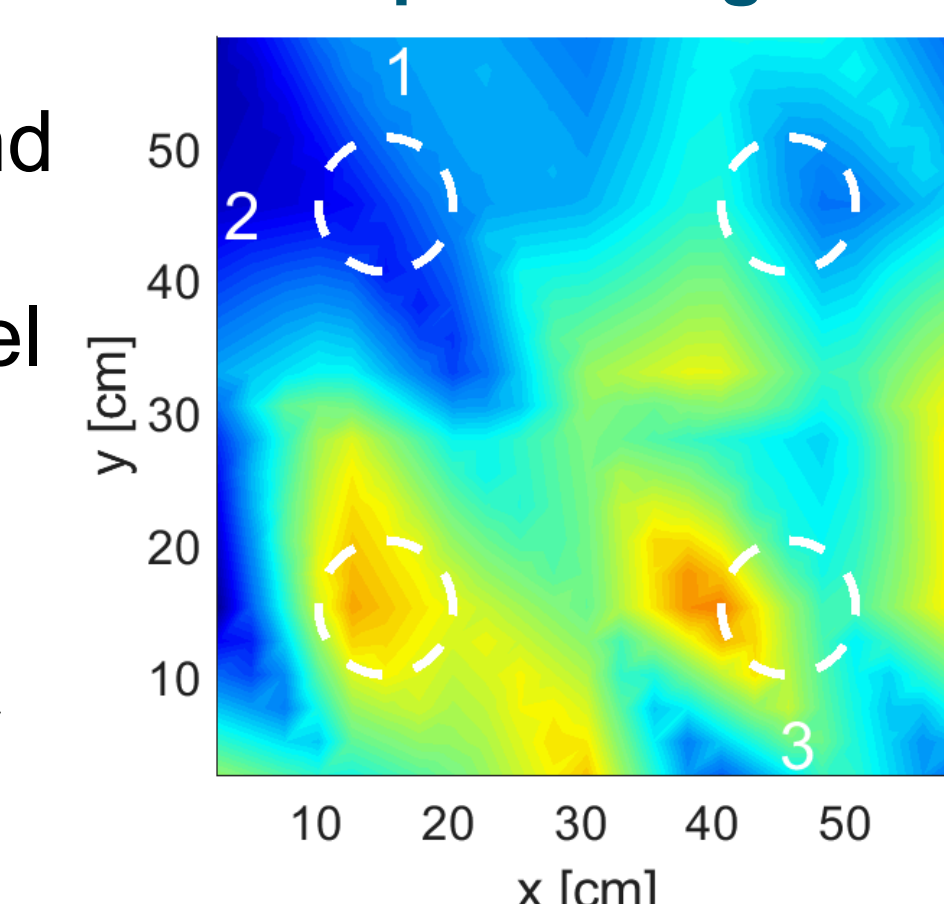| Cast Location | Dimension | Aggregate Location | Reactivity | Reinforcement |
|---|---|---|---|---|
| Vanderbilt | 2' x 2'x 6" | Assorted | Reactive | Non-Reinforced |
| Alabama | 1'x 2'x 1' | North Carolina (NC) | Reactive | Non-Reinforced |
| Alabama | 1'x 2'x 1' | North Carolina (NC) | Control | Non-Reinforced |
| Alabama | 1'x 2'x 1' | Colorado (CO) | Reactive | Non-Reinforced |
| Alabama | 1'x 2'x 1' | Colorado (CO) | Control | Non-Reinforced |
| Nebraska | 1'x 2'x 1' | North Carolina (NC) | Control | Non-Reinforced |
| Nebraska | 1'x 2'x 1' | North Carolina (NC) | Reactive | Non-Reinforced |
| Nebraska | 1'x 2'x 1' | North Carolina (NC) | Reactive | Rebar 1-direction |
| Nebraska | 1'x 2'x 1' | North Carolina (NC) | Reactive | Rebar 2-directions |
| Knoxville | 1.6'x 11'x 3.3' | Unknown | Reactive | Rebar 2-directions |
| Knoxville | 1.6'x 11'x 3.3' | Unknown | Reactive | Rebar 2-directions |
| Knoxville | 1.6'x 11'x 1.7' | Unknown | Reactive | Rebar 2-directions |

## Predictive Modeling

- **Simple average of SBSum Damage Index (DI)**
  - Damage assumed to be at locations where SBSum > mean SBSum for that test. Each location is either Damaged or not Damaged, i.e., D = 0 or 1
- **Neural Network (NN)**
  - Pattern network with three inputs and one output
  - The network had 2 layers with 5 neurons each and contained data from both the Vanderbilt and Alabama North Carolina control specimens
  - 70% of the data was used for training the model while 30% was saved for model testing
- **3-D Analysis**
  - For samples where data was collected on multiple sides, results can be mapped together

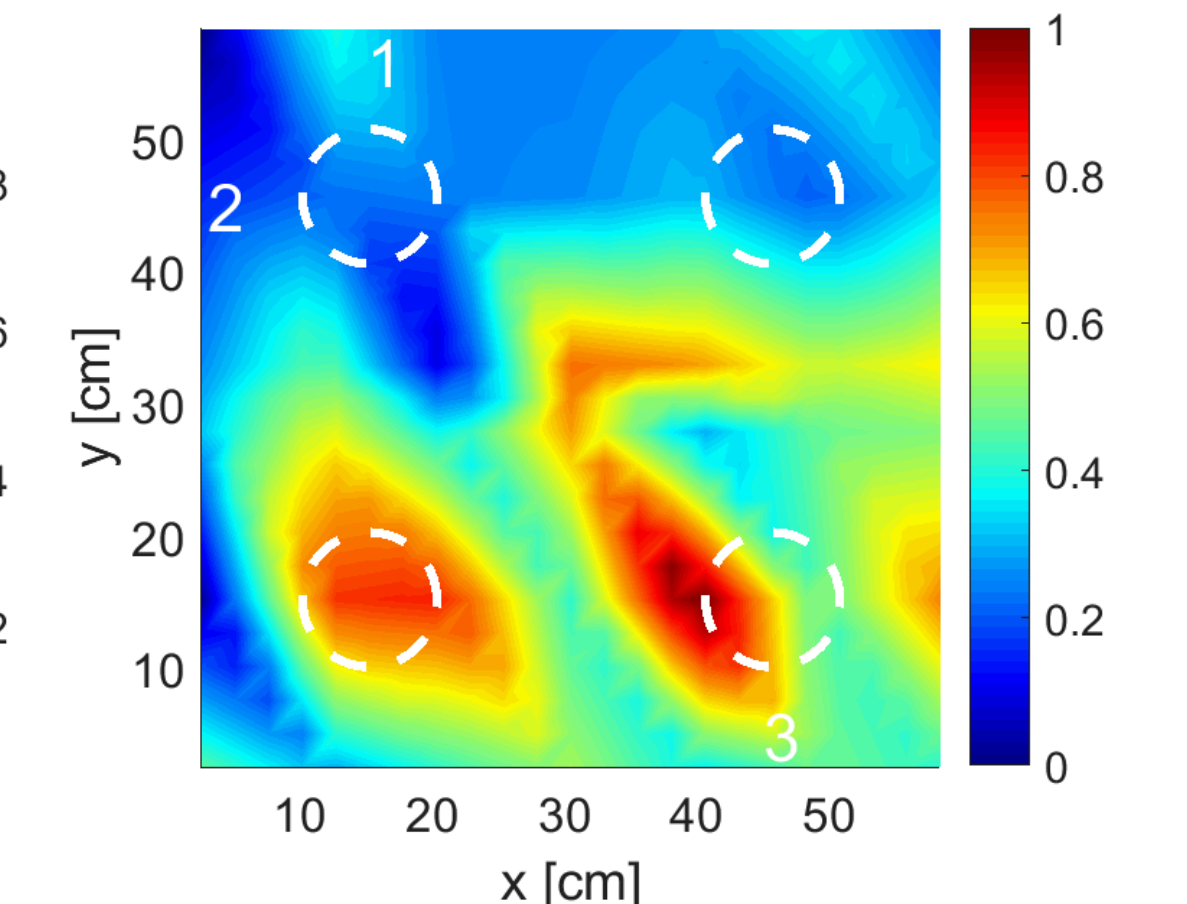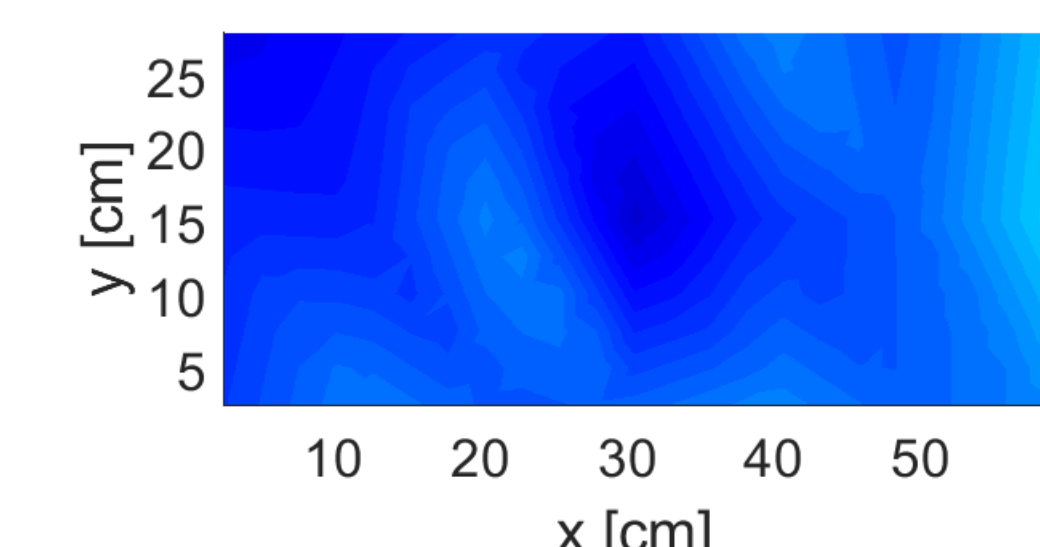**3-D Rendering of Damage in Partial Beam**



**Inputs**    **Layer 1    Layer 2**

$f_{probe}/f_{pump}$

$A_{probe}/A_{pump}$

SBSum

**Output** — Damage Probability



**Simple Average of DI**    **NN Prediction**

**Cross Entropy = 0.1560**    **Cross Entropy = 0.1085**

**NC Control DI**    **NC Control NN Prediction**

**Cross Entropy = 0.000**    **Cross Entropy = 0.000**