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AUTONOMOUS DAMAGE DETECTION IN DOUBLE TRACK STEEL RAILWAY BRIDGES

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- **Outline**

  - ✓ **Damage detection under nonstationary, unknown inputs**
  - ✓ **Why Proper Orthogonal Modes as damage feature?**
  - ✓ **Why ANNs for damage detection?**
  - ✓ **Bridge description**
  - ✓ **Train loads measured by Weigh in Motion sensors**
  - ✓ **Stringer-to-floor beam connection damage detection**

- **Conventional approach to vibration based damage identification:**
  1. Model construction: intact baseline model
  2. Modal identification: typically OMA
  3. Model updating
  4. Damage identification

- **Challenges:**
  1. Modal identification: unknown, non-stationary excitations: train load
  2. Model updating: curse of dimensionality for high number of unknowns
  3. Modal identification and model updating: Measurement noise

- **Our approach:**
  1. Construct a model
  2. Measure a set of non-stationary loads
  3. Find features in response that has correlation to non-stationary loads
  4. Use proper orthogonal modes of measured response as damage features
  5. Train an ANN:
     I. use few train loads and the model to train the network; and
     II. the trained network will generalize for response to unknown future loads

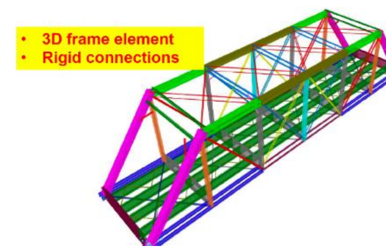
- **Work done:**
  1. Detailed FE model of the bridge was constructed
  2. Axles loads were measured for 81 trains
  3. ANNs were trained
  4. ANNs were tested for generalization to unknown loads

- **Why proper orthogonal modes?**
  1. Could be calculated automatically
  2. Robust to measurement noises
  3. Easy to interpret

- **Why ANNs:**
  1. Extract subtle changes from changes in damage features
  2. Robust to curse of dimensionality
  3. Need for minimal user training
  4. Generalize well for unknown inputs

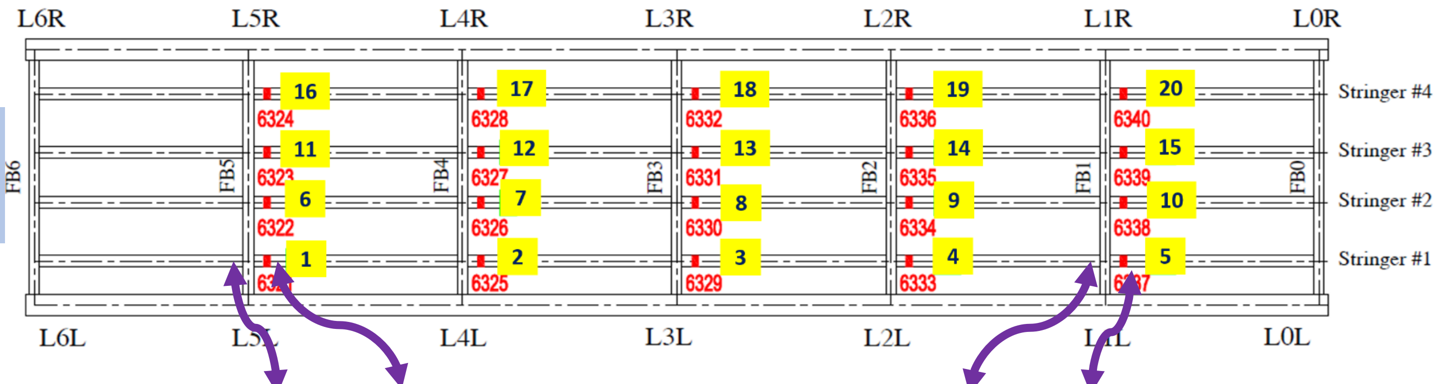
- **Bridge description** **[Owner plans, reports]**
  - ✓ Double track
  - ✓ Riveted construction
  - ✓ Pin and eyebar

- **Stringer-to-floor beam connection damage detection – Analytical based**
  - MATLAB code
  - Reads train loading excel files
  - Model trains in SAP2000
  - Extracts and stores strains
  - 81 trains to the west, one track, 50 axles/train

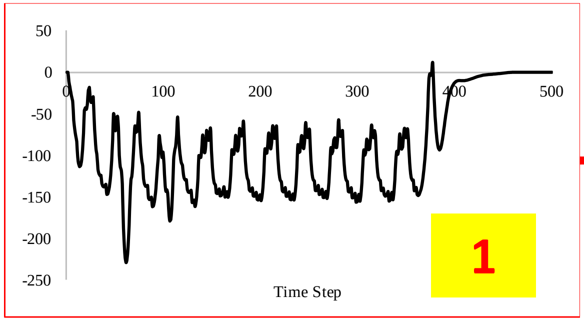


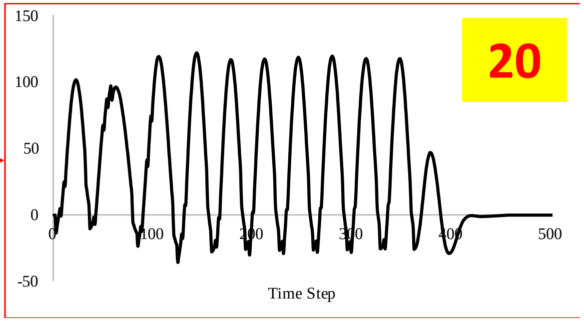
- Stringer-to-floor beam connection damage detection – **Analytical based**

Stress time-history @ marked locations

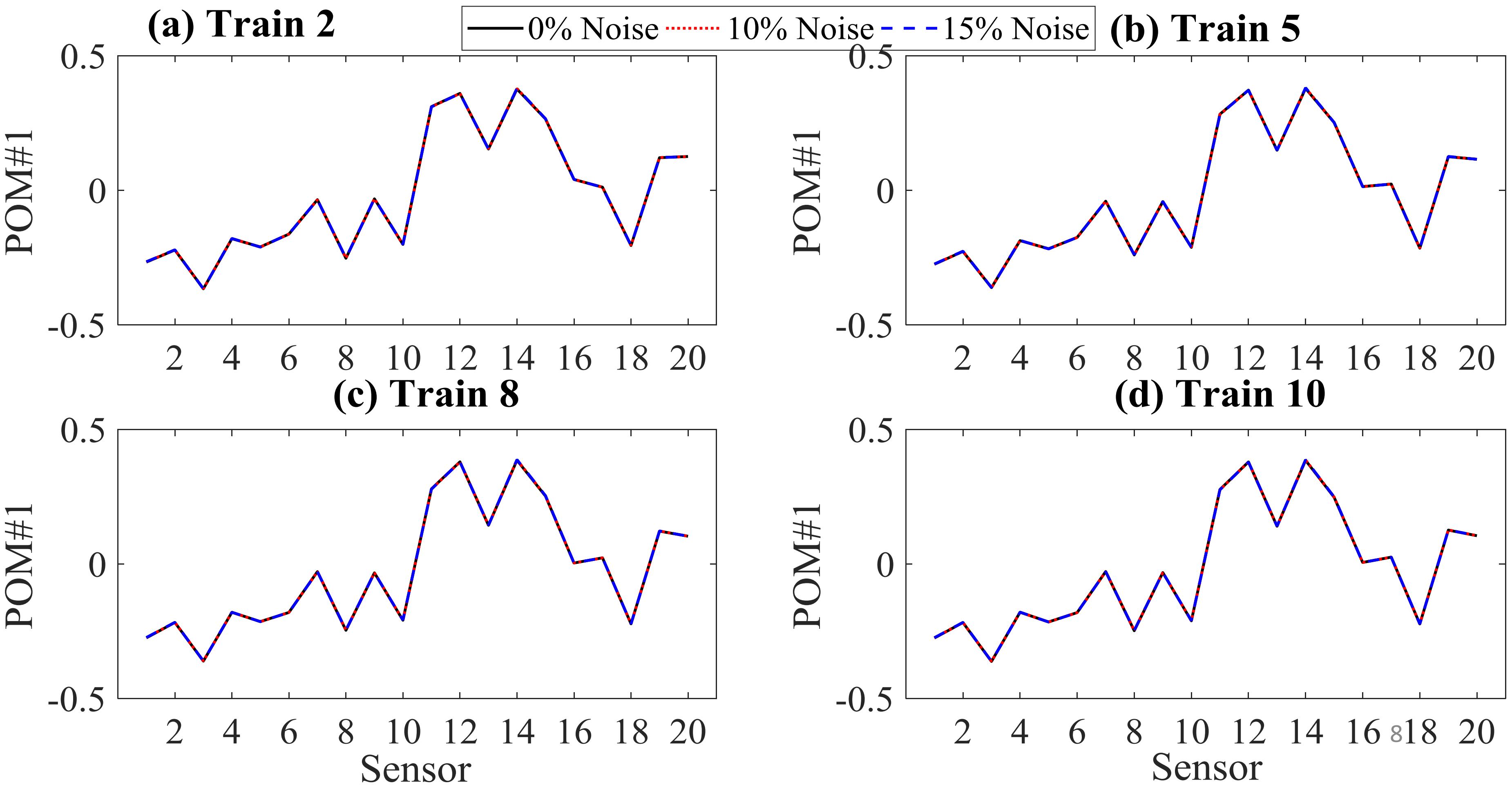


One sensor capture damage on both sides

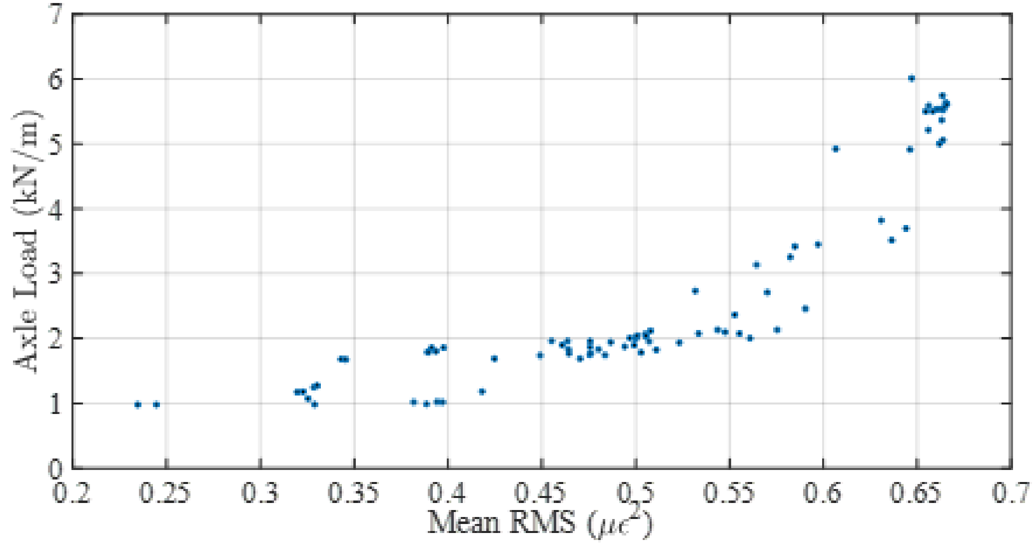


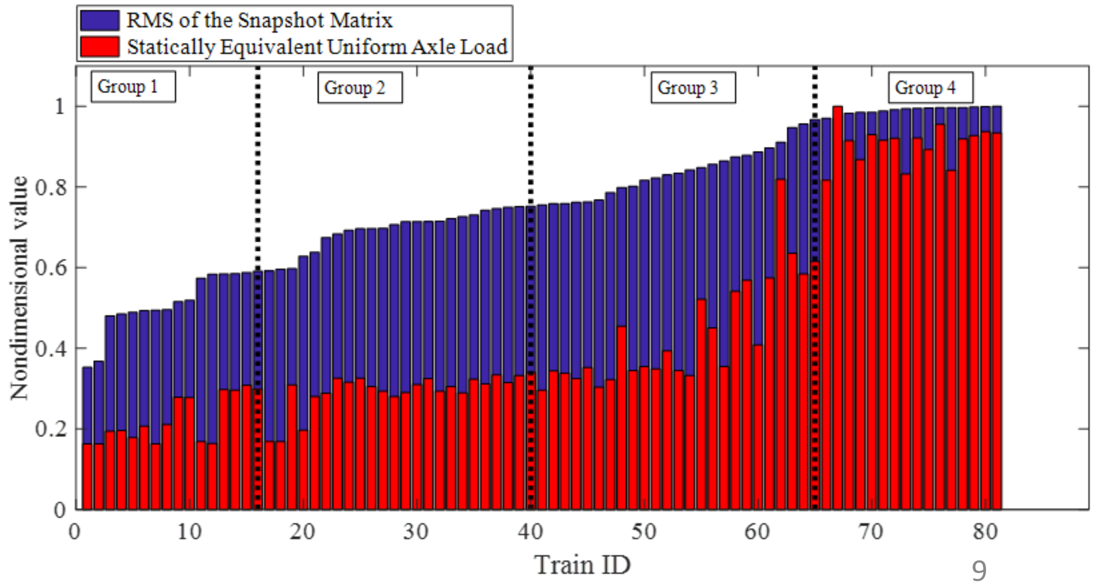


- **POMs of 4 train loads for various noise to signal ratio levels:**

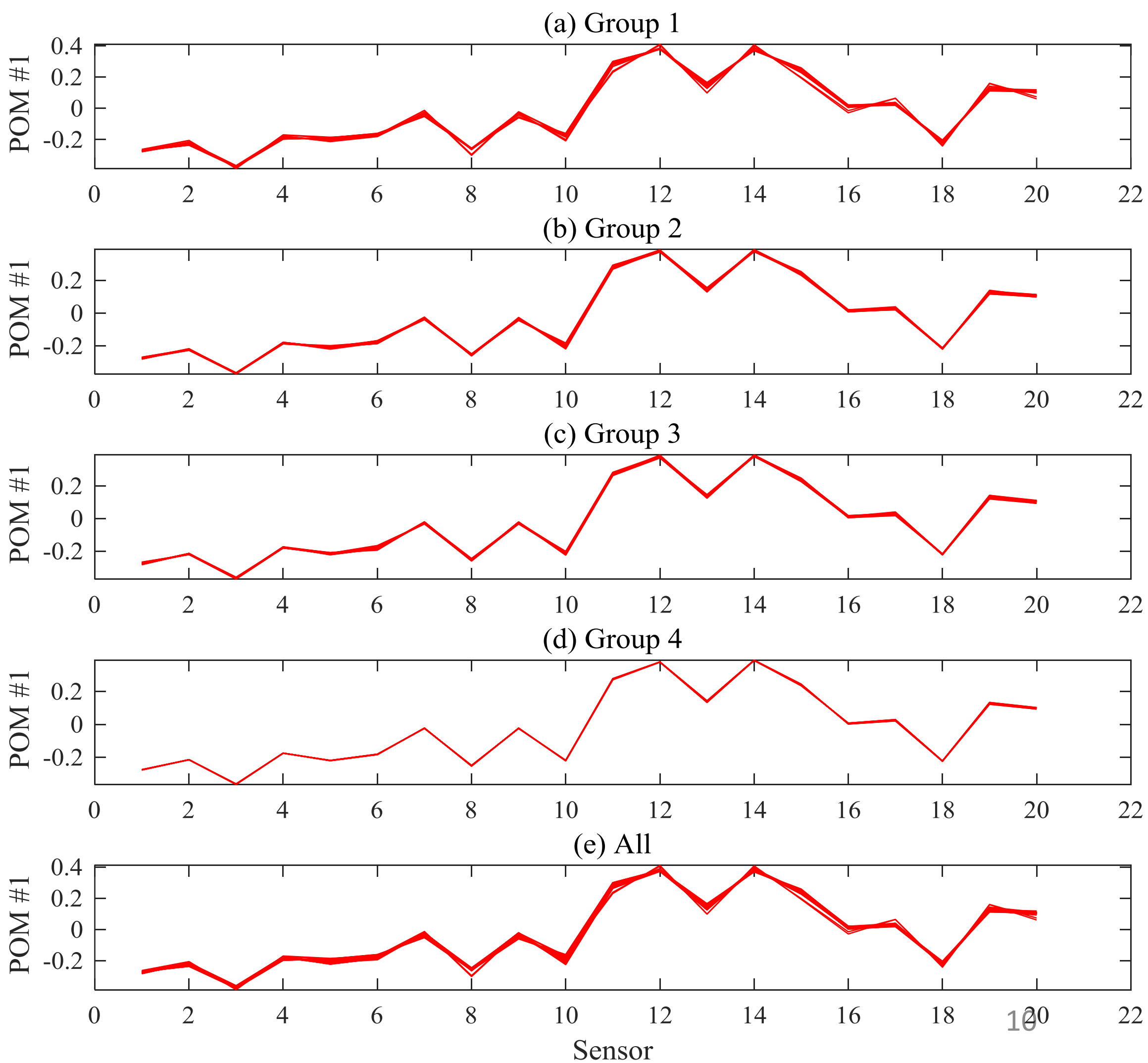


- **How to treat unknown inputs?**
  1. Find features of response which are correlated with loads
  2. Train a clustering/classification algorithm
- **What we did:**
  1. Measured train axle loads using Weigh in Motion (WIM)
  2. Used the measured axles loads to calculated the structural response
  3. Compared response from the model to find a correlation between response features and axle loads
  4. **Mean RMS of channels is the feature**

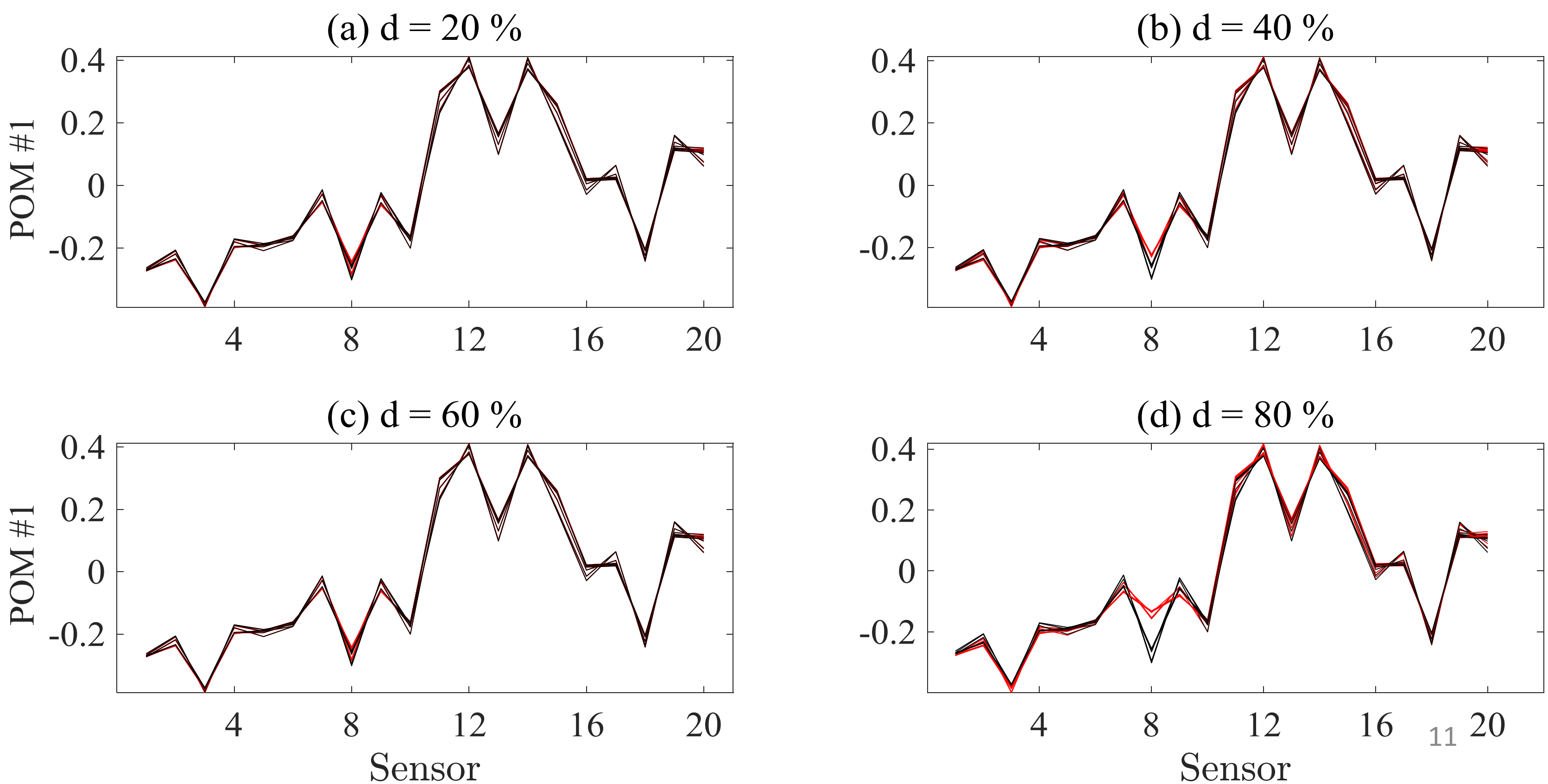




- **POMs of each of 4 groups vs all POMs together:**
  1. You notice categorizing POMS based on RMS values reduces variability
  2. We used POMs of Group 4 for ANN training



- **POMs of Group 4 and various damage levels:**
    1. The higher the damage level, the more pronounced the variation in POM
    2. Smaller damage levels not detectable: there is still discrepancy stemming from load variations
    3. **We used ANNs to detect small damage levels**



- **Stringer-to-floor beam connection damage detection – Analytical based**

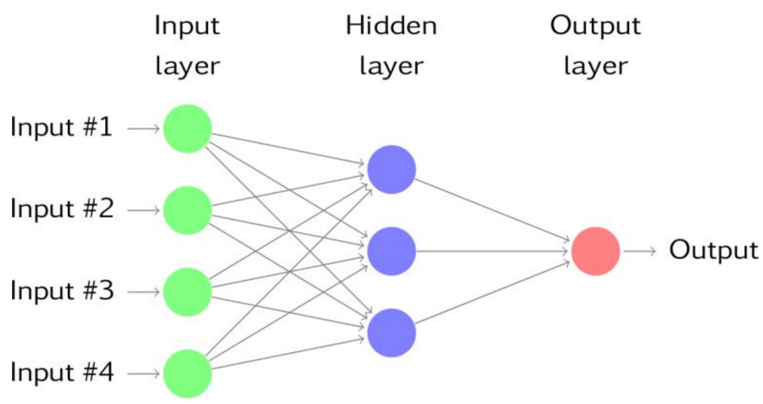
  - ✓ **POMs influenced by:**
    - **Loads**
    - Environmental effects (future work)
    - **Damage**

  - ✓ **ANNs:**
    - Half of trains in Group 4 were used for training
    - Half of trains in Group 4 were used for testing (successful)
    - Trains from Group 1, 2, and 3 yielded bad results

- **Stringer-to-floor beam connection damage detection – Analytical based**

POMs

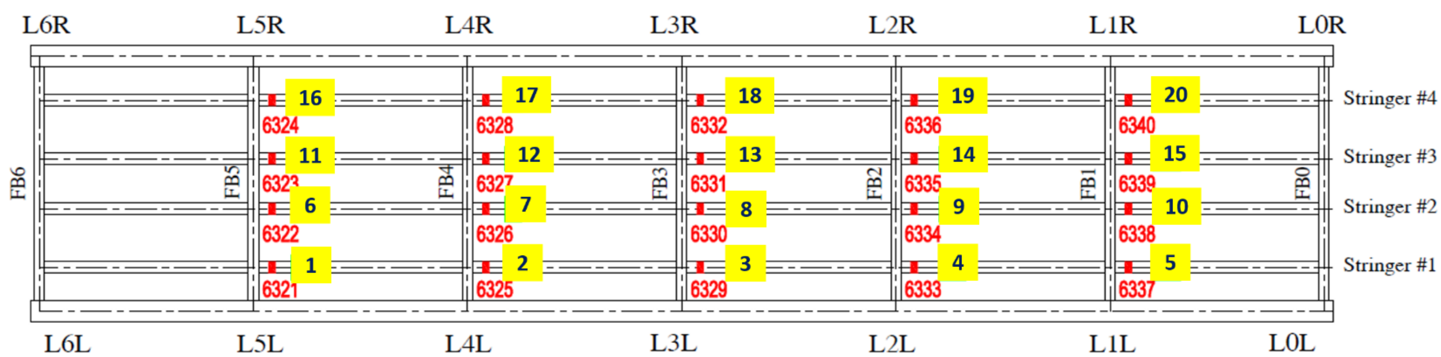
Damage/load scenarios



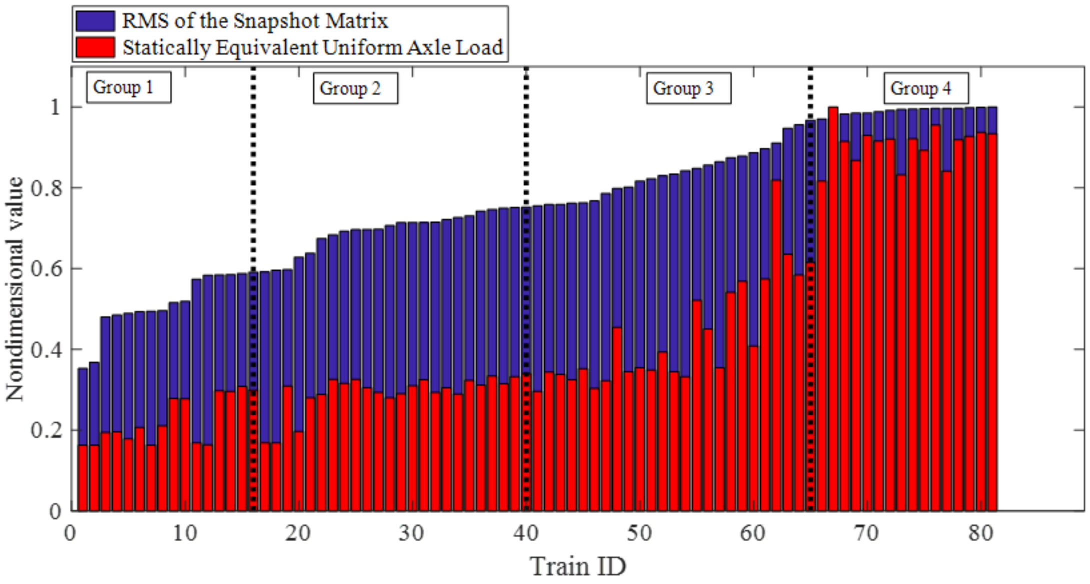
Damage location/intensity

Bending stiffness reduction of: 10:10:100%

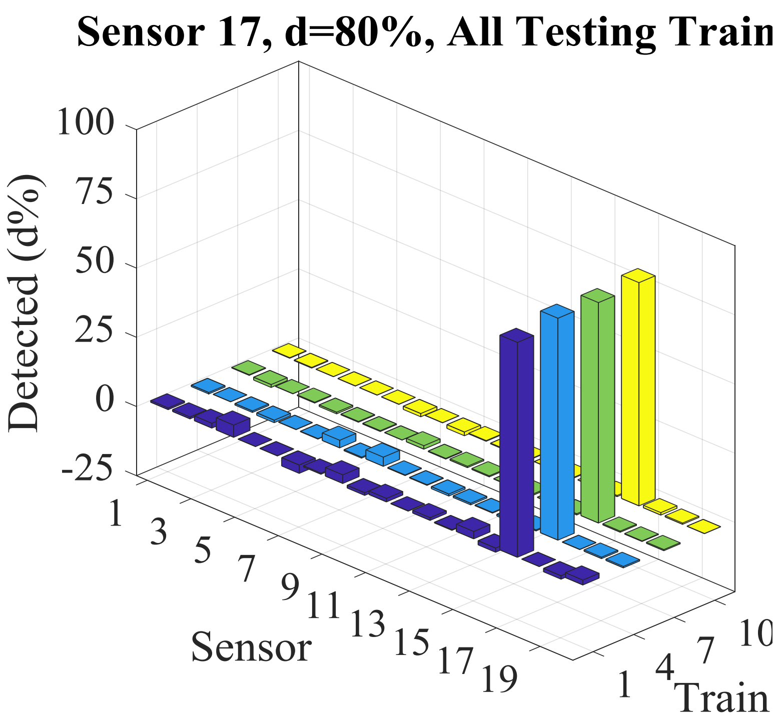
200 damage scenarios/train

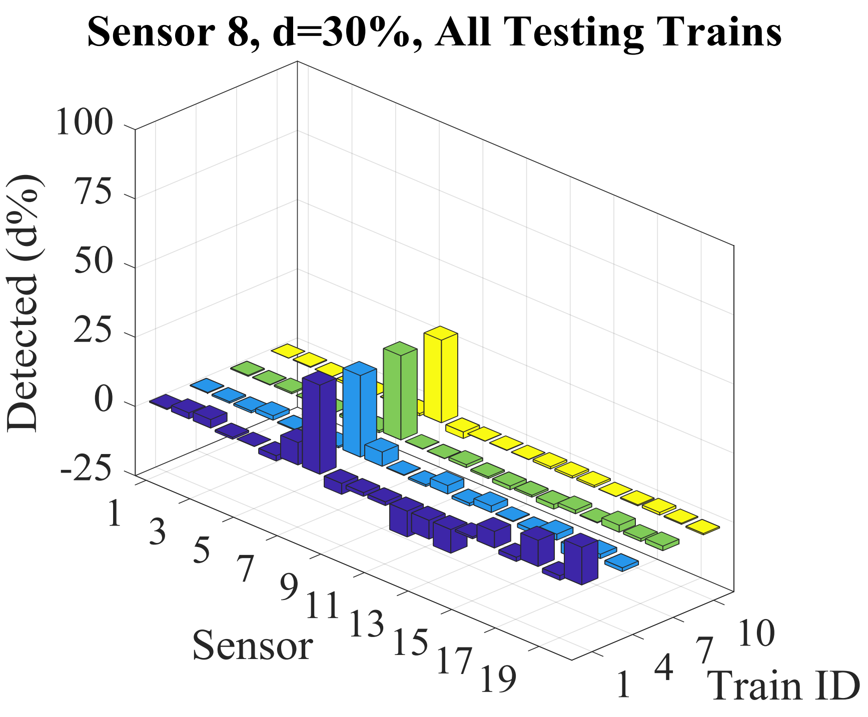


- ✓ **In total we measured 81 train loads**
  - The trains were categorized, and divided into 4 groups
    - We trained ANN using 6 train loads, all from Group 4
      - We test ANN using 4 trains, from Group 4

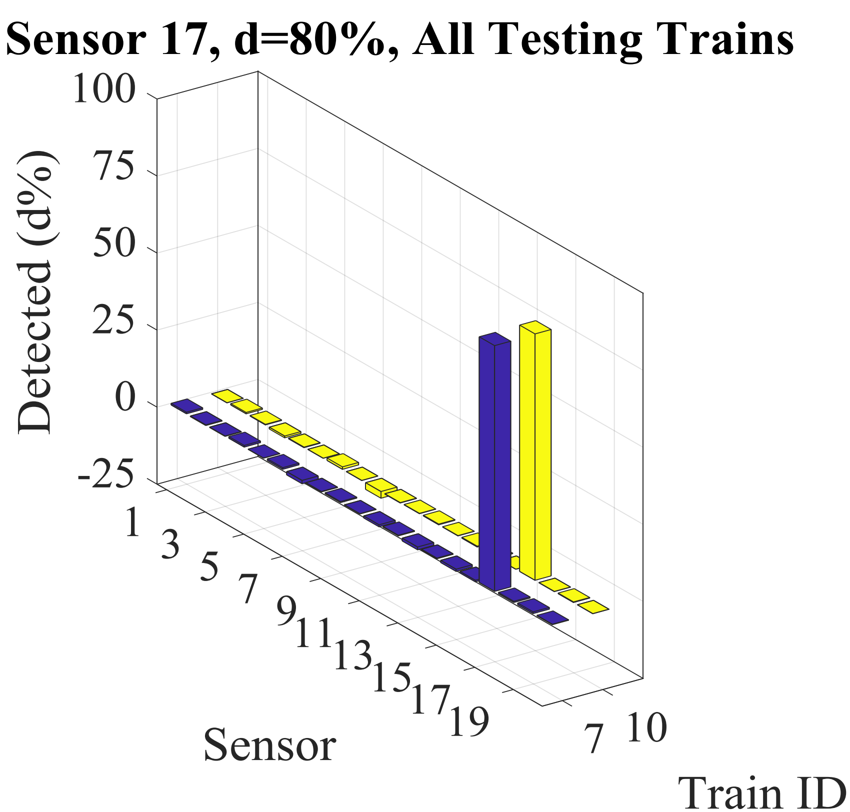


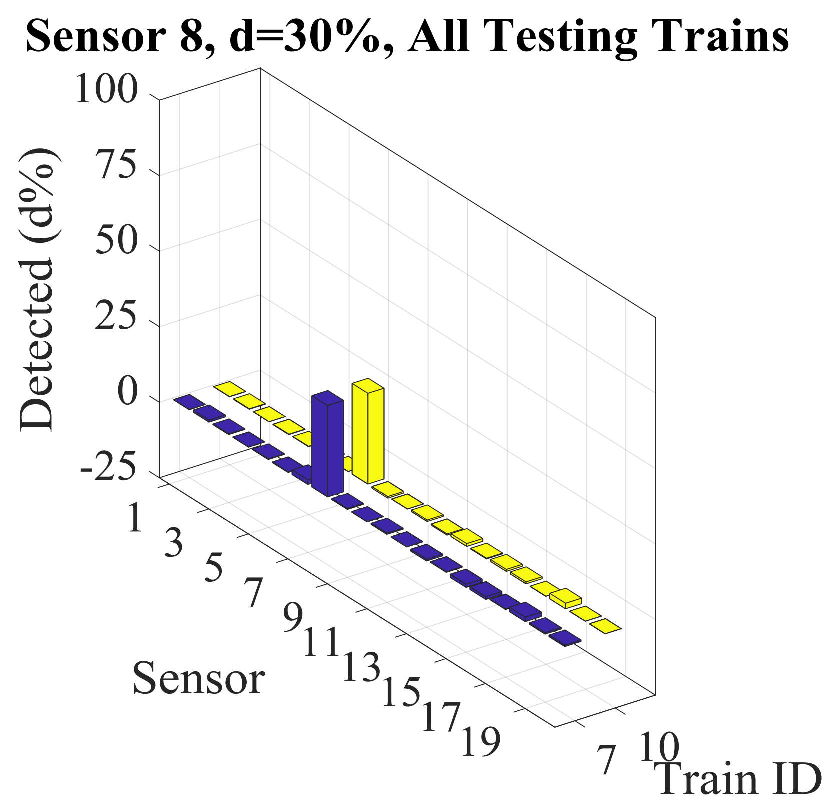
- **Stringer-to-floor beam connection damage detection**
- **6 trains used in ANN training**
- **The testing trains were not used in ANN training**





- **Stringer-to-floor beam connection damage detection**
- **8 trains used in ANN training**
- **The testing trains were not used in ANN training**





- Stringer-to-floor beam connection damage detection
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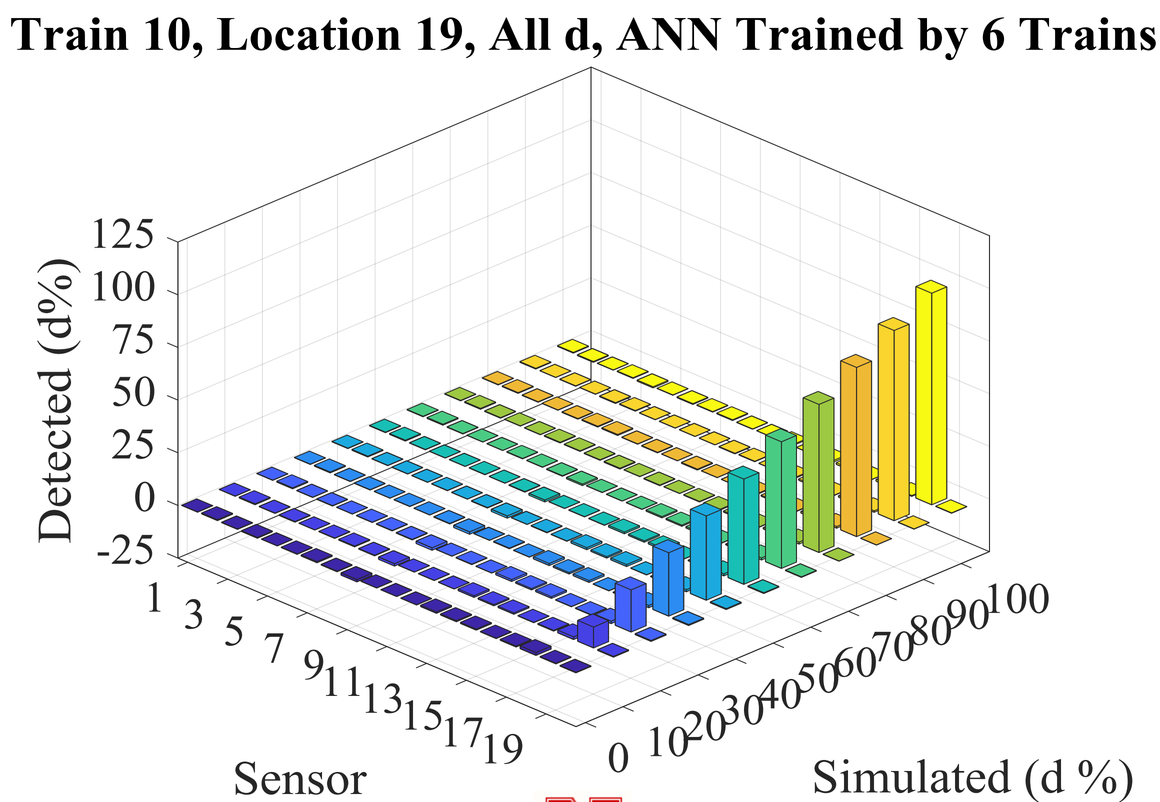

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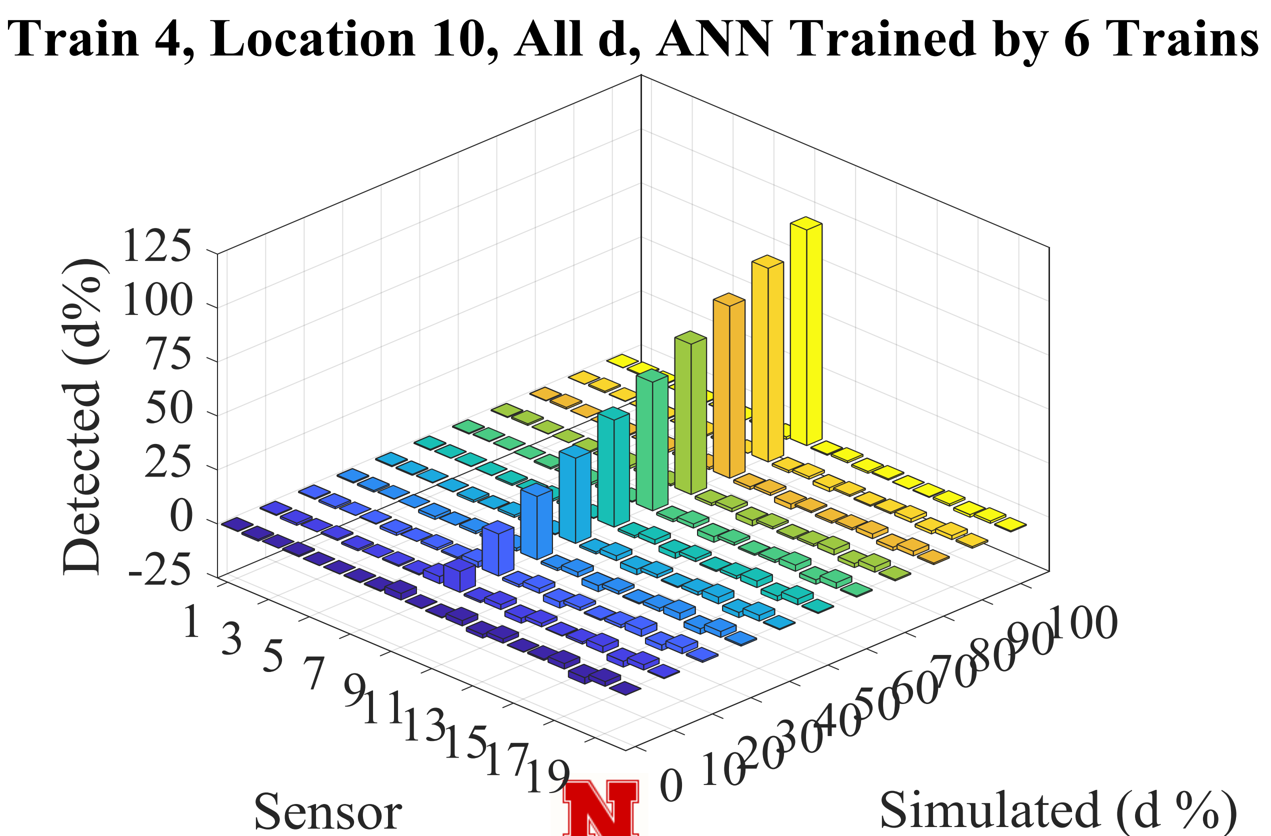
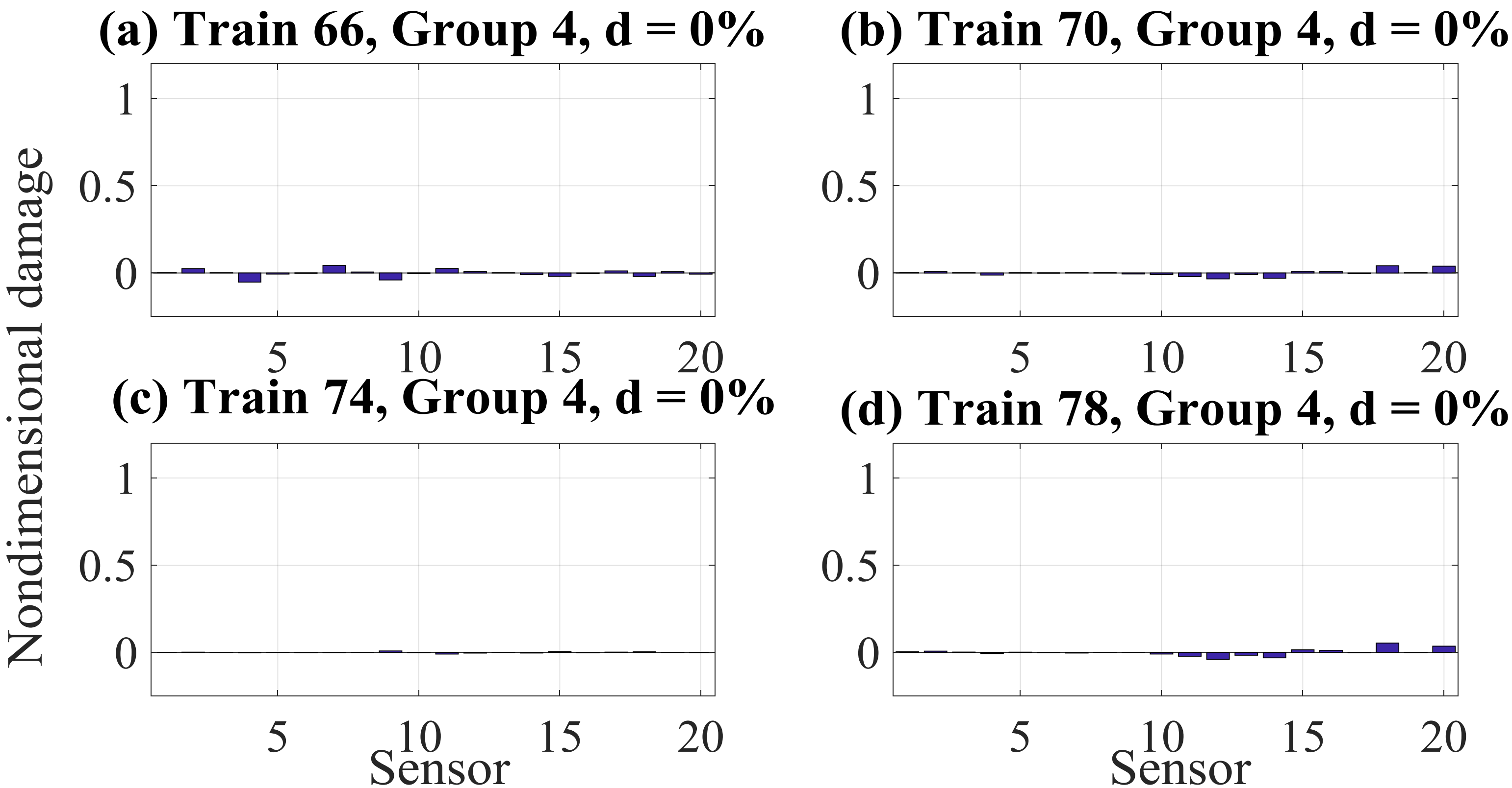
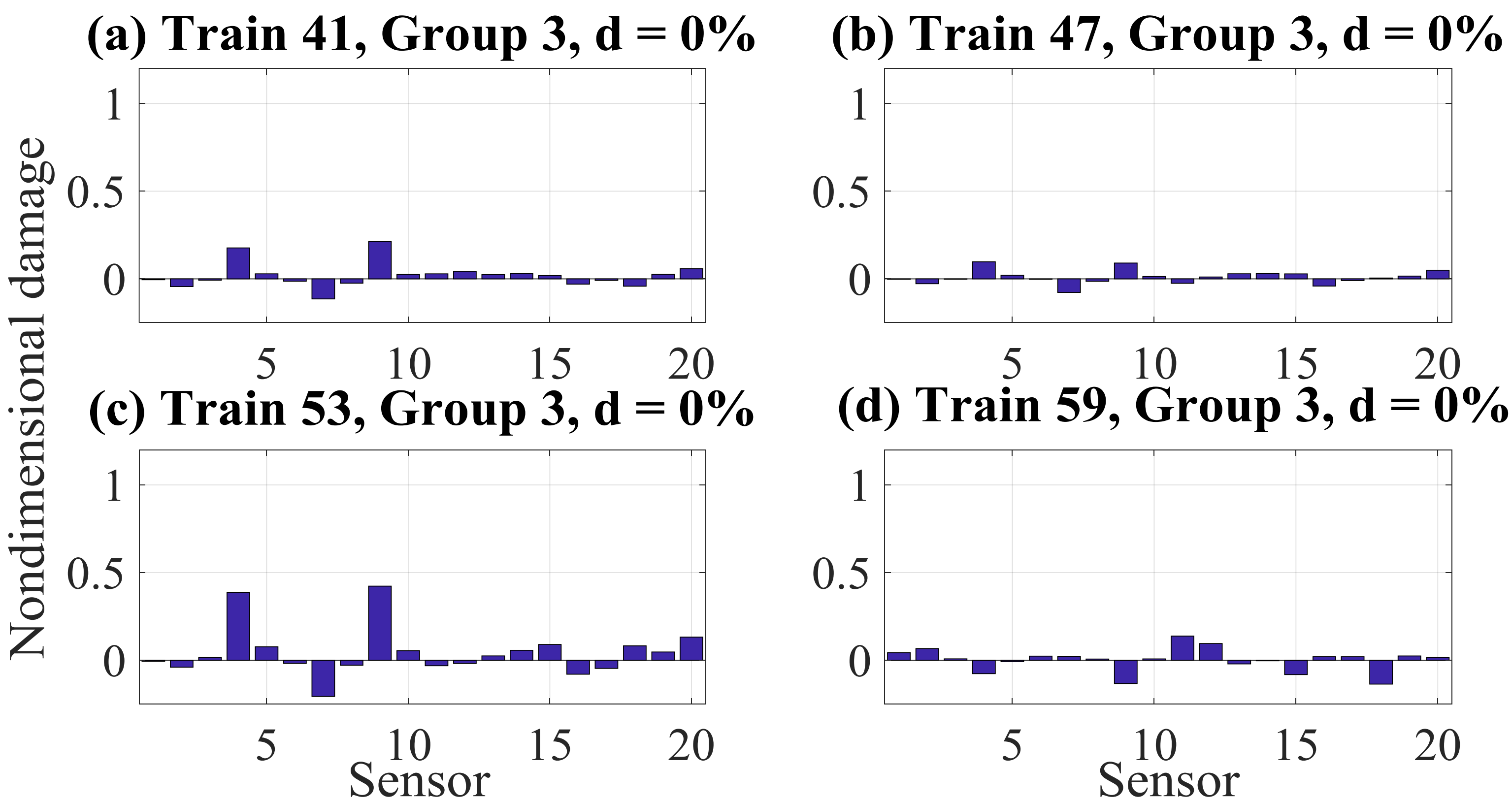


- **Stringer-to-floor beam connection damage detection**
- **The testing trains were not used in ANN training**



- **What if the testing trains are selected from other groups?**
- **The testing trains were not used in ANN training**



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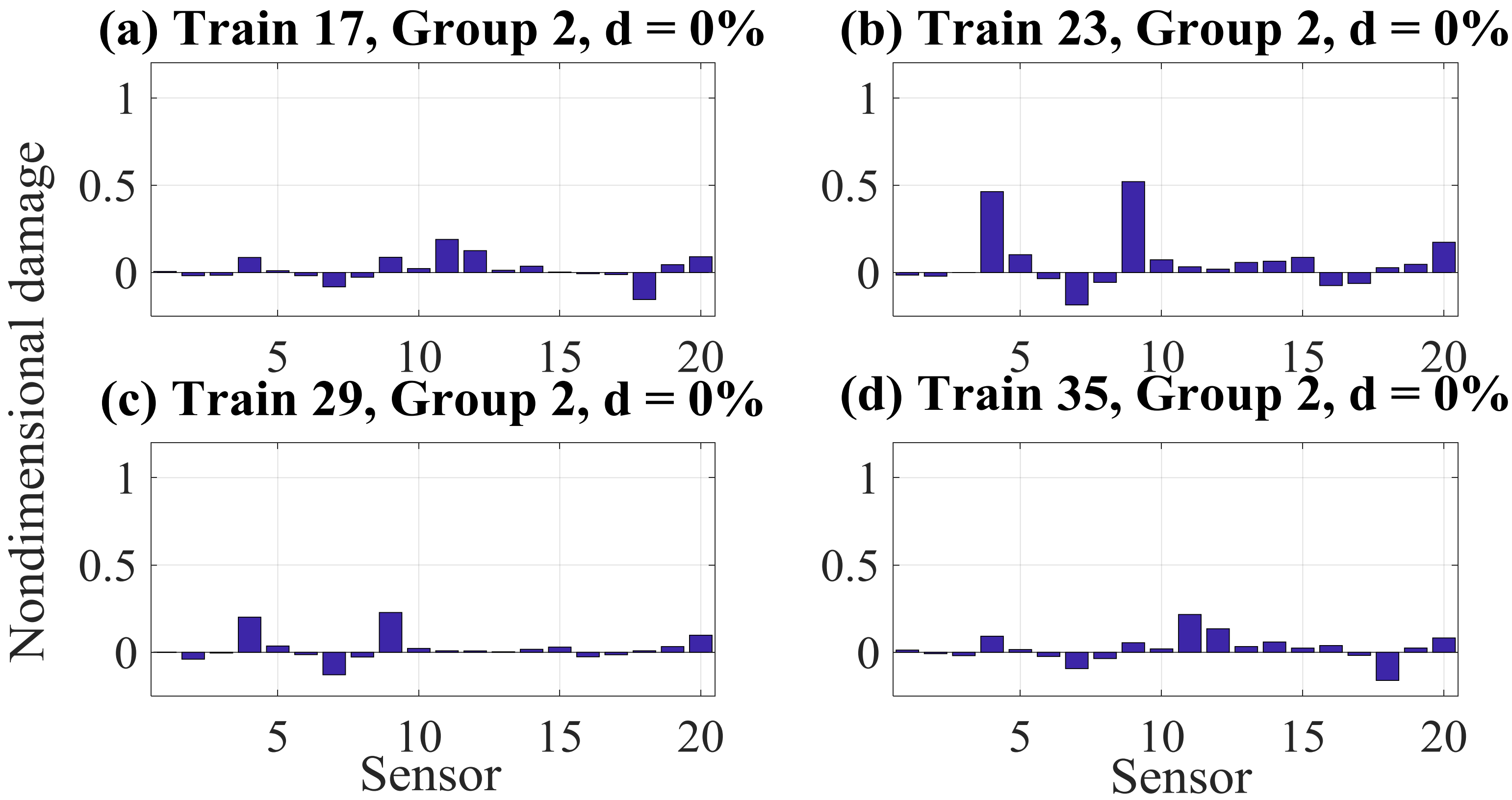

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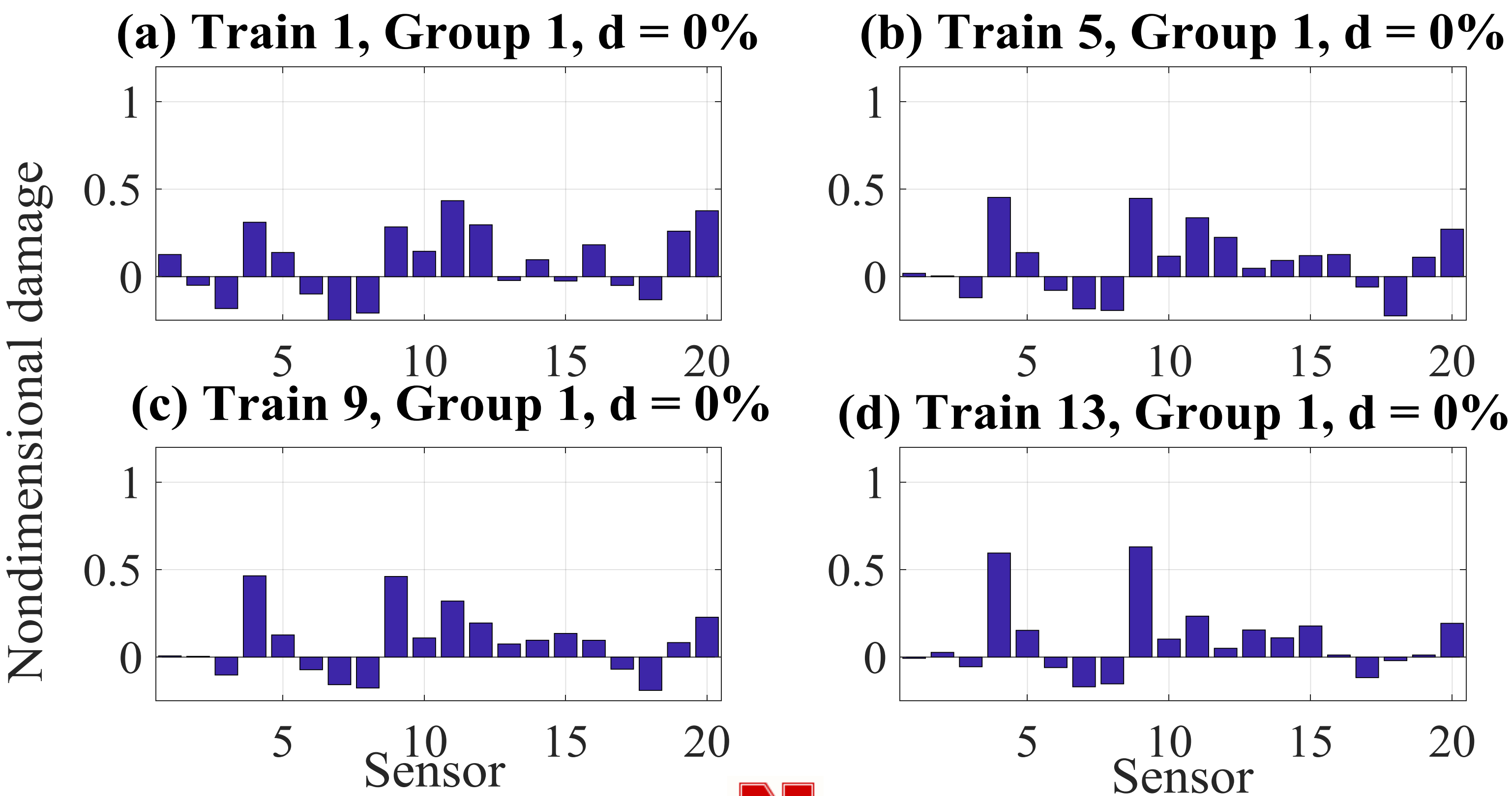

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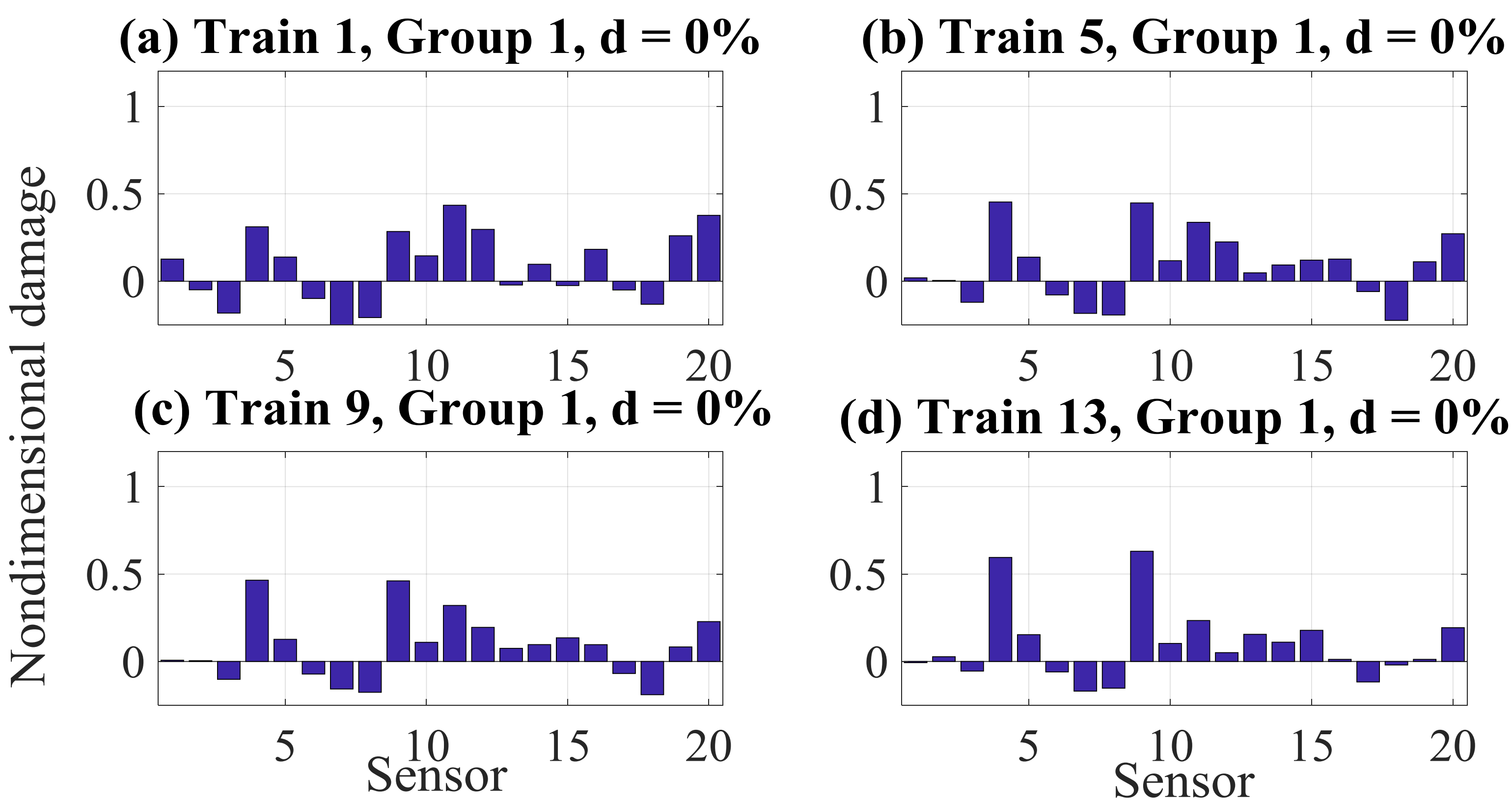
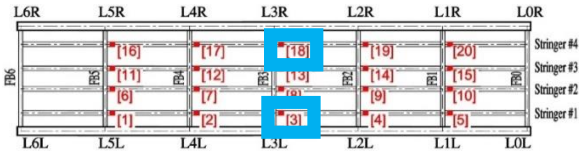
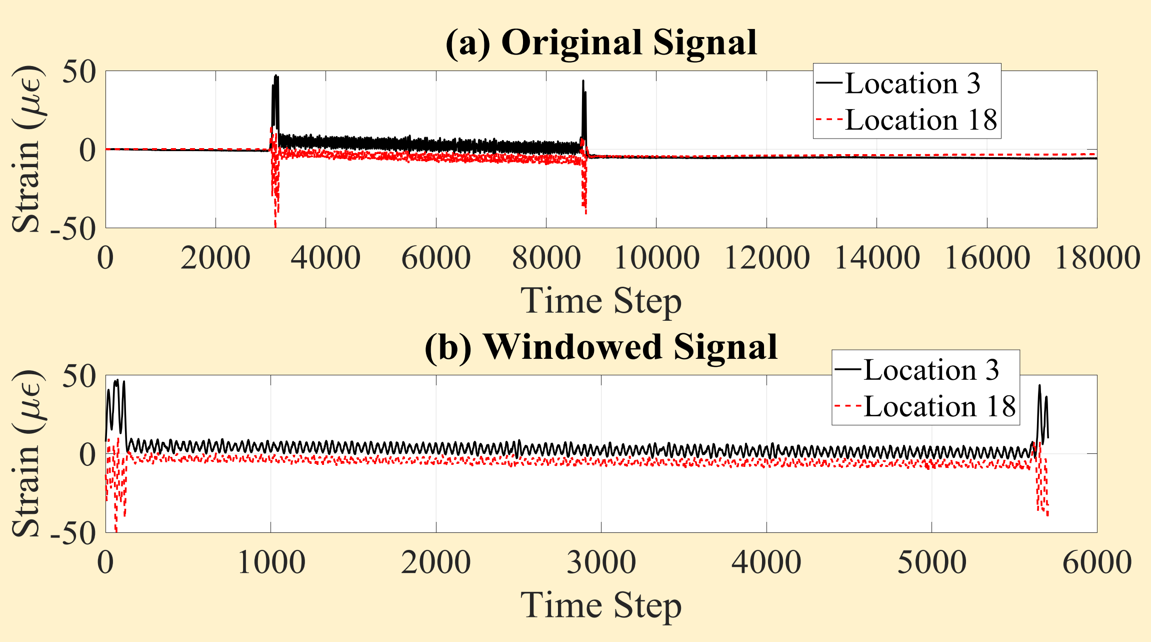


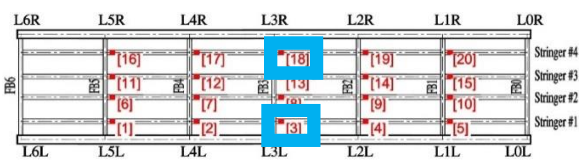
- **Stringer-to-floor beam connection damage detection – Field based**

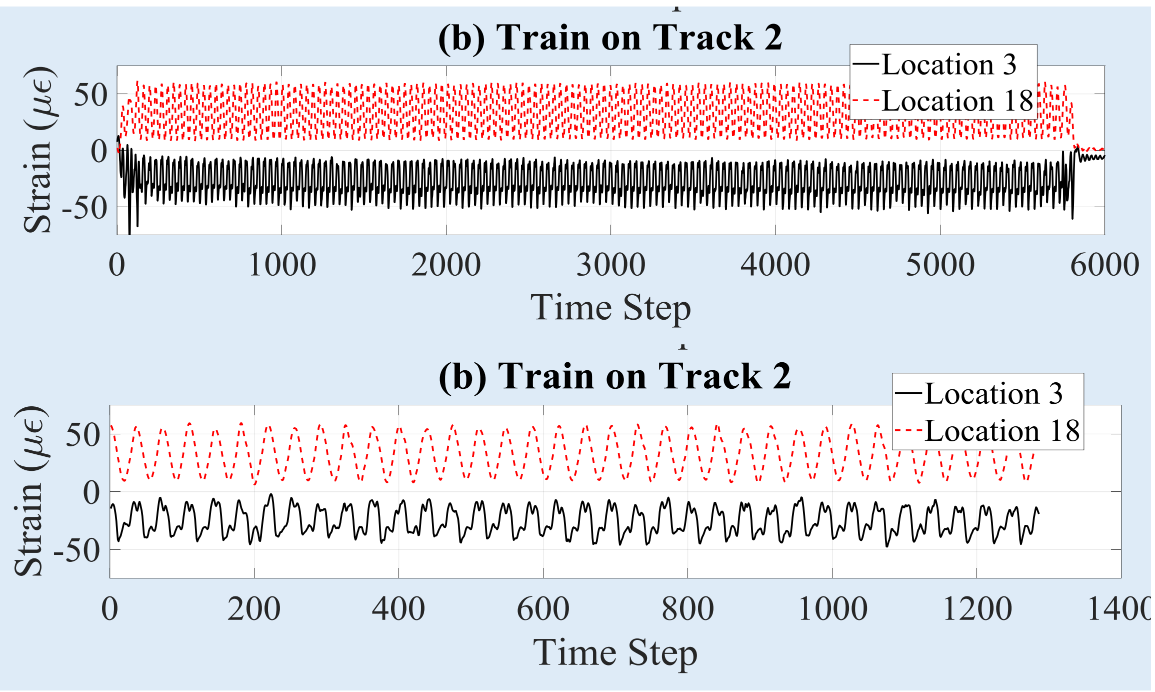
- **Stringer-to-floor beam connection damage detection – Field based**
  - ✓ **POMs/loading effects:**
    - Data cleansing





- **Stringer-to-floor beam connection damage detection – Field based**
  - ✓ **POMs/loading effects:**
    - Data classifying and peak-picking

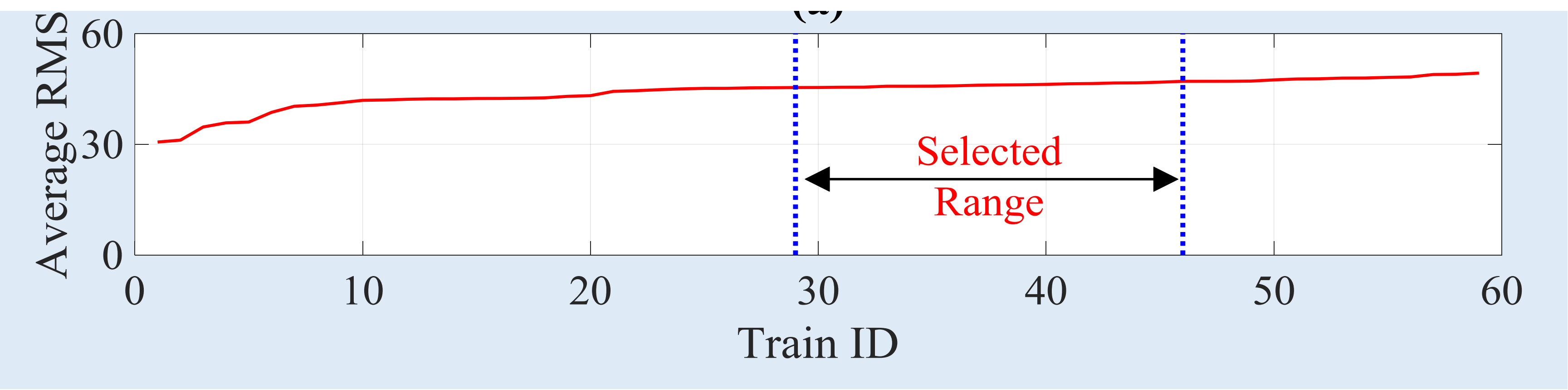




- **Stringer-to-floor beam connection damage detection – Field based**

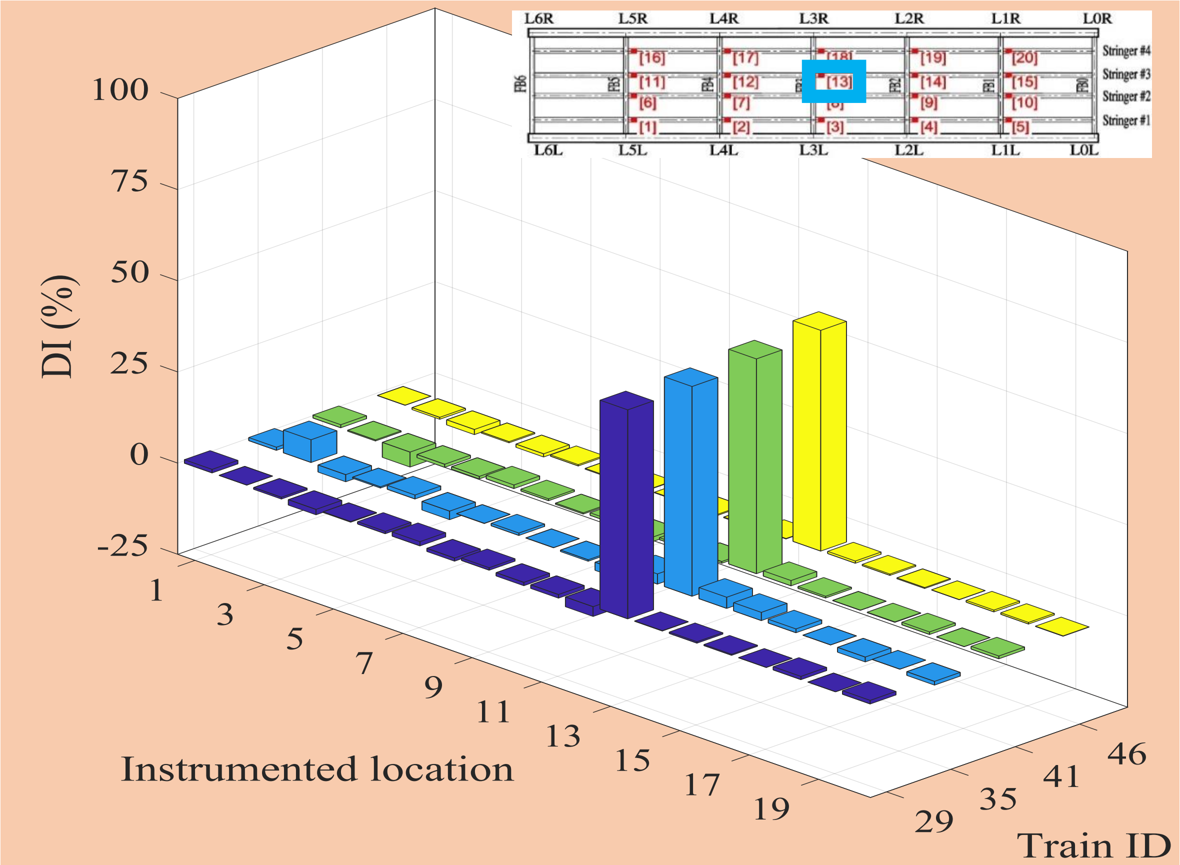
✓ **ANNs:**

- Damage scenarios via reduced strains
- ANNs trained using healthy and damaged POMs
- ANNs tested using signal POMs



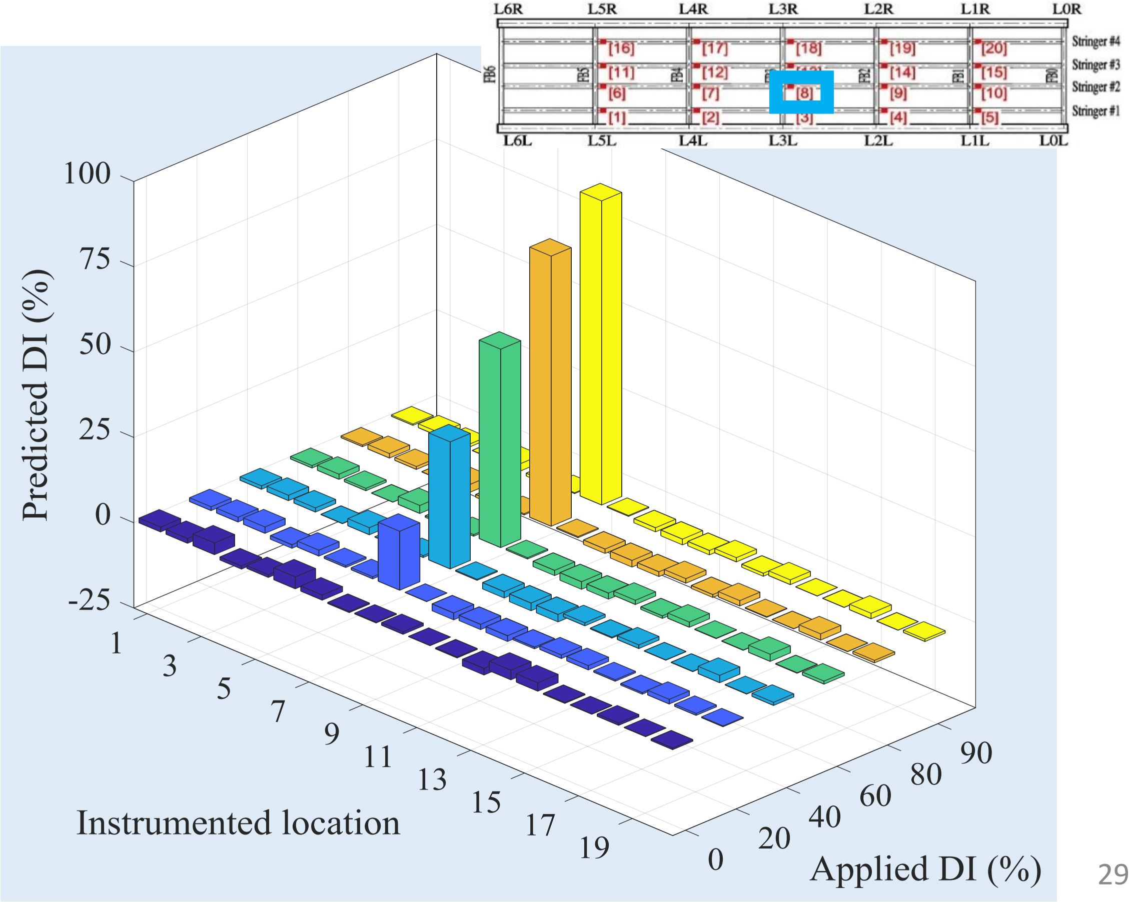
- **Stringer-to-floor beam connection damage detection – Field based**

All Testing Trains
Location 13
DI = 60%



- **Stringer-to-floor beam connection damage detection – Field based**

Train 29
Location 8
All DIs



- **Conclusions**
  - ✓ Damage detected via strains induced by unknown, nonstationary external inputs
  - ✓ Proper orthogonal modes are robust damage features
  - ✓ Artificial Neural Network is required for identification of large number of damage indices
  - ✓ Features for classification of unknown input from the response matrix were found

Questions?

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