HUMAN-MACHINE COLLABORATION FRAMEWORK FOR BRIDGE HEALTH MONITORING

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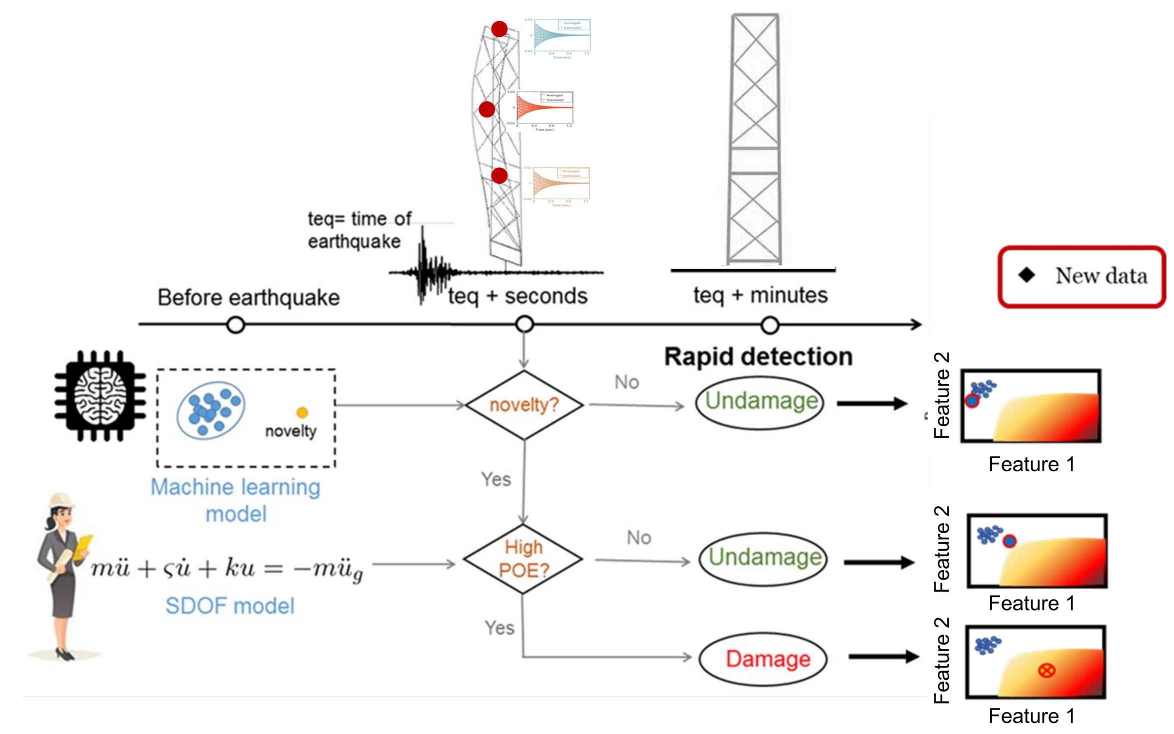
INTRODUCTION

Structural health monitoring (SHM) of bridges is becoming essential as the civil infrastructures of US are aging. According to the 2018 report card for California's infrastructures, 6.2% of California's bridges are structurally deficient and the largest percentage of bridges in "Poor" condition in the nation belongs to California. Moreover, approximately 50% of bridges in the state have exceeded their design life. The backlog of recommended maintenance, repair, and replacement continues to grow. Therefore continued health monitoring of these bridges are essential for safe operation and for prioritizing replacement. The monitoring of these vulnerable structures becomes more critical after natural disasters such as an earthquake. The loss of accessibility due to damages and closures of the transportation network can greatly affect the rescue and recovery of a city after such a disaster. Utilizing the advances in remote sensing, computing technologies, and data science presents an effective and feasible way of structural monitoring of the bridges.

This research project aims at developing a bridge structural health monitoring (SHM) framework using acceleration data of instrumented bridges. The framework is called the human-machine collaboration (H-MC) framework. According to the national research council, the human-machine collaboration is a model in which humans co-work with artificial intelligence to complete specific tasks. The purpose is to use the particular strengths of both types of intelligence, and even physical capabilities, to compensate for the weaknesses of the other. When developed successfully, this framework will improve post-earthquake response and mitigate economic losses associated with major seismic events.

The H-MC framework for bridge SHM is developed for rapid assessment of existing bridges



PROJECT AIMS

AIM 1: Select a computational bridge model for study.

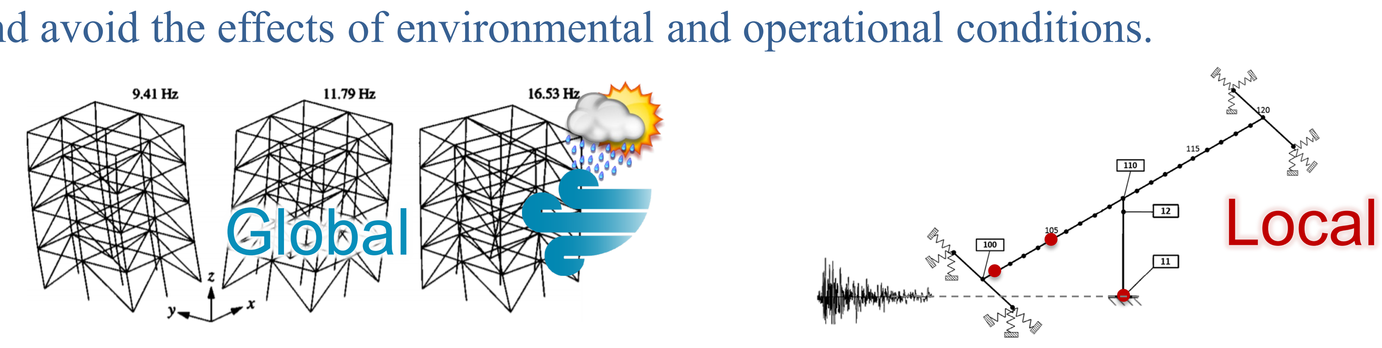
AIM 2: Develop and verify a H-MC framework for bridge structures.

AIM 3: Apply the developed framework on selected CSMIP structures.

BACKGROUND

Bridge SHM can be improved using a data-driven approach.

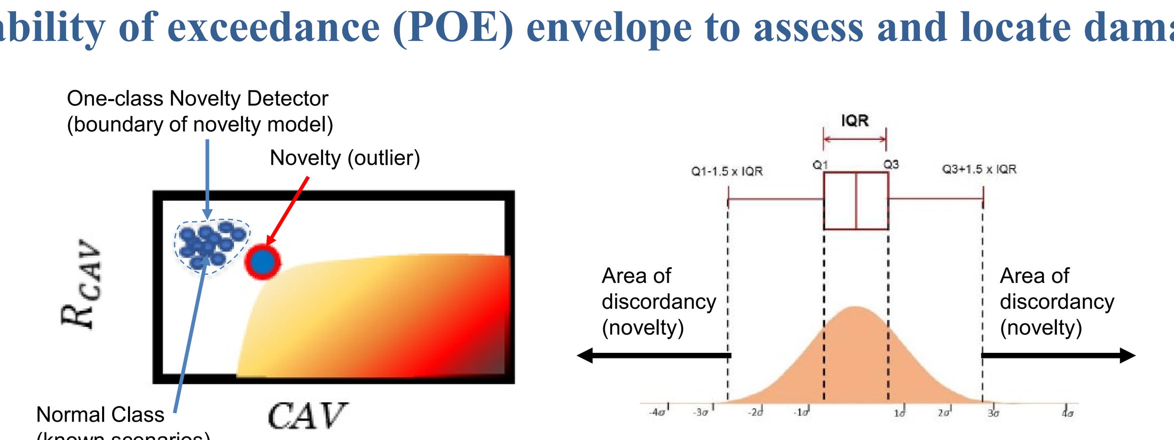
- In contrast to modal property methods, a data-driven approach can identify local damage and avoid the effects of environmental and operational conditions.



Low-dimensional damage features, such as CAV and its related features, can be suitable for machine learning applications with limited data.

$$CAV = \int_0^T |\ddot{u}(t)|dt \quad R_{CAV} = \frac{CAV_s}{CAV_l} \quad \Delta_{CAV} = \left(\frac{|A_s - A_l|}{A_l}\right) \times 100$$

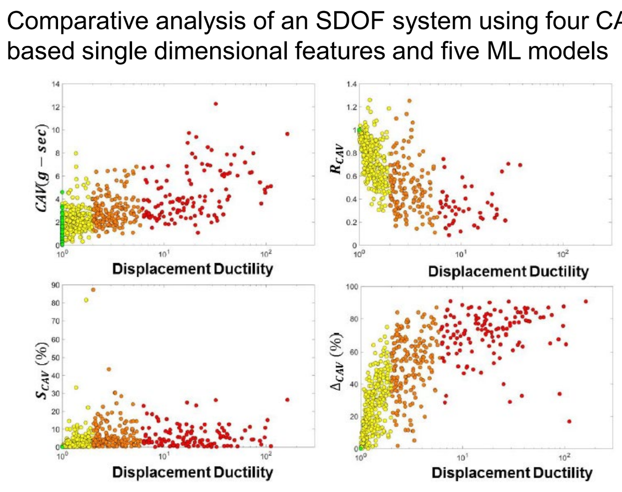
Novelty detection, an unsupervised machine learning method, is used in conjunction with a probability of exceedance (POE) envelope to assess and locate damage.



This data-driven approach has been used successfully for identifying damage severity and damage location in buildings.

- The H-MC framework correctly labeled 15 instrumented buildings as damaged and undamaged and eliminated false positive detections.

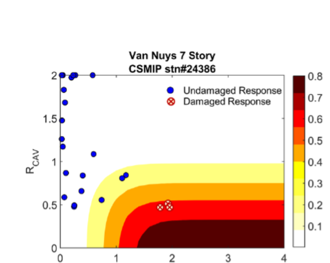
Comparative analysis of an SDOF system using four CAV-based single dimensional features and five ML models

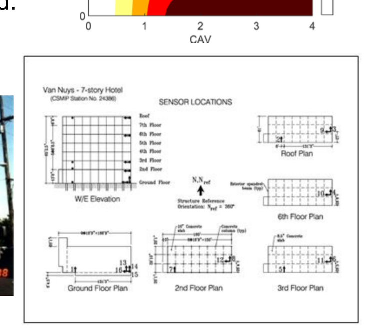


Damage state accuracy: 96% – 84%
Location accuracy: 97.5% – 93%

Accuracy of damage assessment for MDOF systems using a novelty model with POE envelope for CAV and R_{CAV}

The H-MC framework accurately detects damage for the Van Nuys 7-story hotel (CSMIP station 24386) after the damaging event occurred.

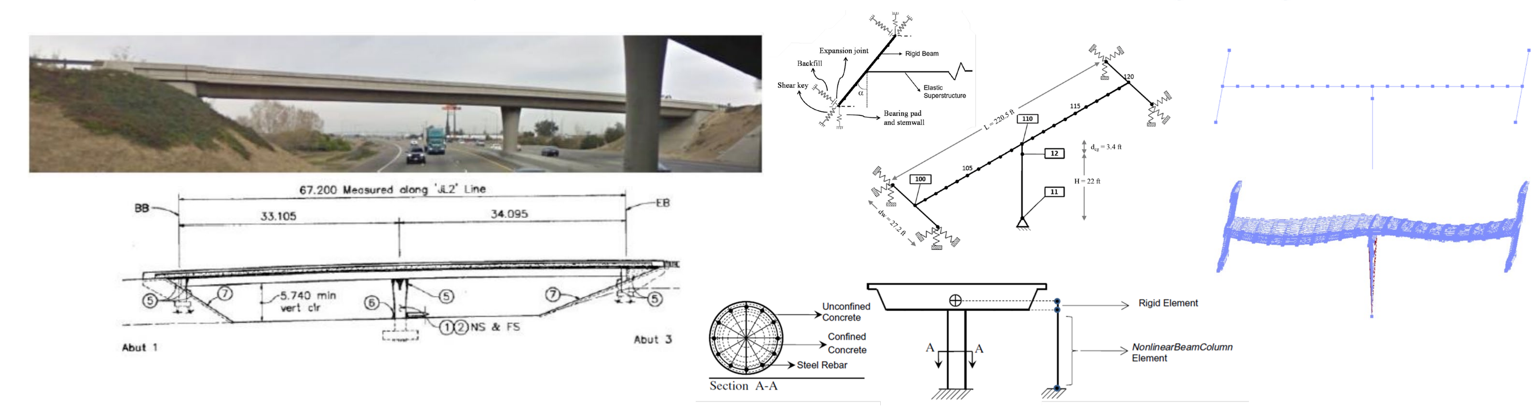




METHODOLOGY

Project Aim 1:

Benchmark analytical model: **Jack Tone Road Overcrossing Bridge**



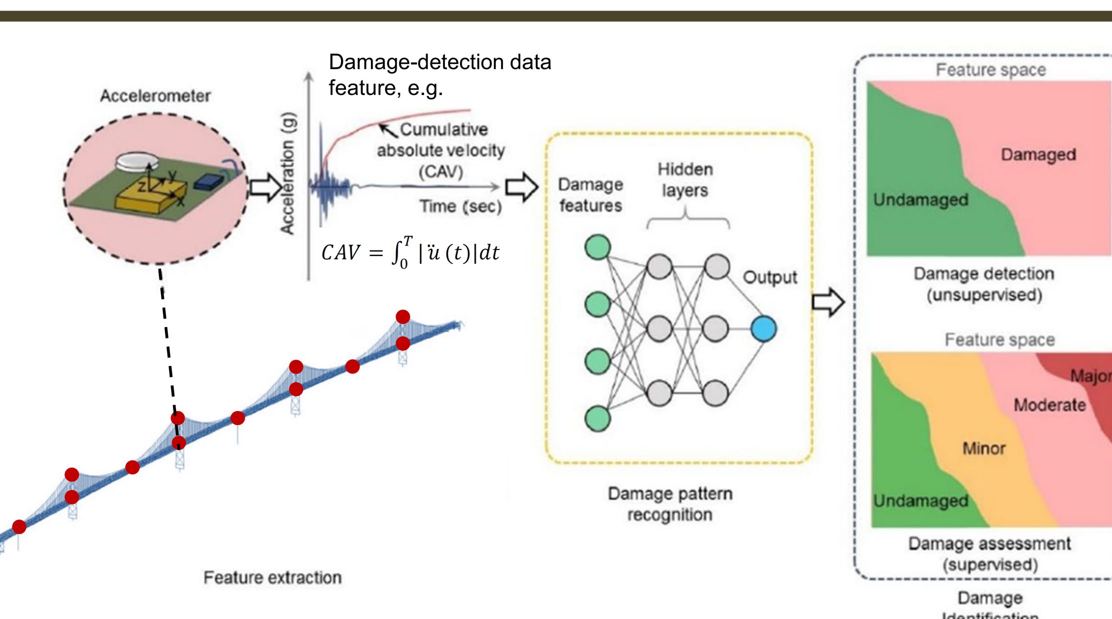
Bridge Info
- Bridge type: Two-span reinforced concrete highway bridge
- Location: San Joaquin County, California
- Geometry: ~220 ft span, ~25 ft height
- Support: single column bent and seat-type abutments

Finite Element Model Info
- Deck: 2 symmetric 110.25 ft spans with 20 nodes along deck length
- Column: Nonlinear beam-column with nonlinear fiber-based beam finite elements at 10 quadrature points
- Abutments: nonlinear spring and gap element passive backfill response and expansion joints with EPP shear key response

# of spans	2
Column bent	Single-column
Column radius	33.1 in.
Column height	22.0 ft.
Abutment	Seat type
Seat length	33.85 in.
Superstructure concrete	$f'_c = 5\ ksi$, $E_c = 4030.5\ ksi$
Column bent concrete and reinforcing materials	Concrete: 5 ksi Steel: ASTM A706
Reinforcement details of column bent cross-section	Long.: 44 #11 (bundles of 2) $\rho_l = 2.00\%$ Trans.: Spiral, #6 @ 3.34 in.

Project Aim 2:

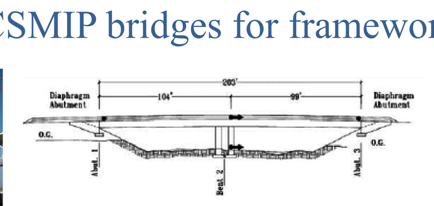
A framework is developed using acceleration data from the instrumented structure to assess the damage state of the structure



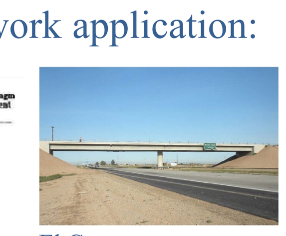
Project Aim 3:

Proposed CSMIP bridges for framework application:

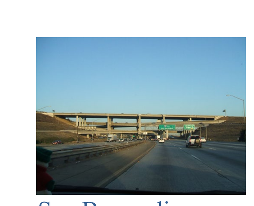

Vallejo – Carquinez/I80 West Bridge



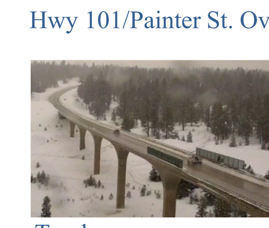
Lake Crowley – Hwy 395 Bridge

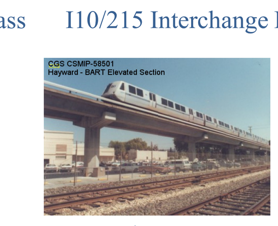

El Centro – Hwy8/Meloland Overpass


Rio Dell – Hwy 101/Painter St. Overpass


San Bernardino – I10/215 Interchange Bridge

For each bridge:
a) Preprocess raw data to remove noise.
b) Extract the damage features.
c) Develop a novelty model
d) Develop a probability of exceedance (POE) function
e) Run the developed algorithm to assess damage condition of the structure.


Truckee – I80/Truckee River Bridge



Hayward – BART Elevated Section

CONCLUSION

Results of the conducted investigation are expected to automate the process of damage detection and assess and notify the risk associated with each structure immediately after an earthquake. It will provide a quantitative basis for decision making regarding operation, load carrying capacity, cost and time required for repair. Furthermore, it will aid in emergency response and recovery efforts which are essential after any natural disasters. This will, in turn, highlight the importance of bridge instrumentation and encourage future instrumentation efforts.

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