Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

Noise robustness of an operational modal-based structural damage-detection scheme using impact-synchronous modal analysis

Pei Yi SIOW, Zhi Chao ONG, Shin Yee KHOO, Kok-Sing LIM

Key Words: Impact-synchronous modal analysis, Frequency response function, Principal component analysis, Unsupervised learning, Damage detection

Cite this as: Pei Yi SIOW, Zhi Chao ONG, Shin Yee KHOO, Kok-Sing LIM, 2023. Noise robustness of an operational modal-based structural damage-detection scheme using impact-synchronous modal analysis. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 24(9):782-800. https://doi.org/10.1631/jzus.A2200620

Introduction

Problem Statement

■ Unsupervised methods require damage-sensitive features for accurate damage detection.

■ The Frequency Response Functions (FRFs) is damage-sensitive upstream modal data but is complex.

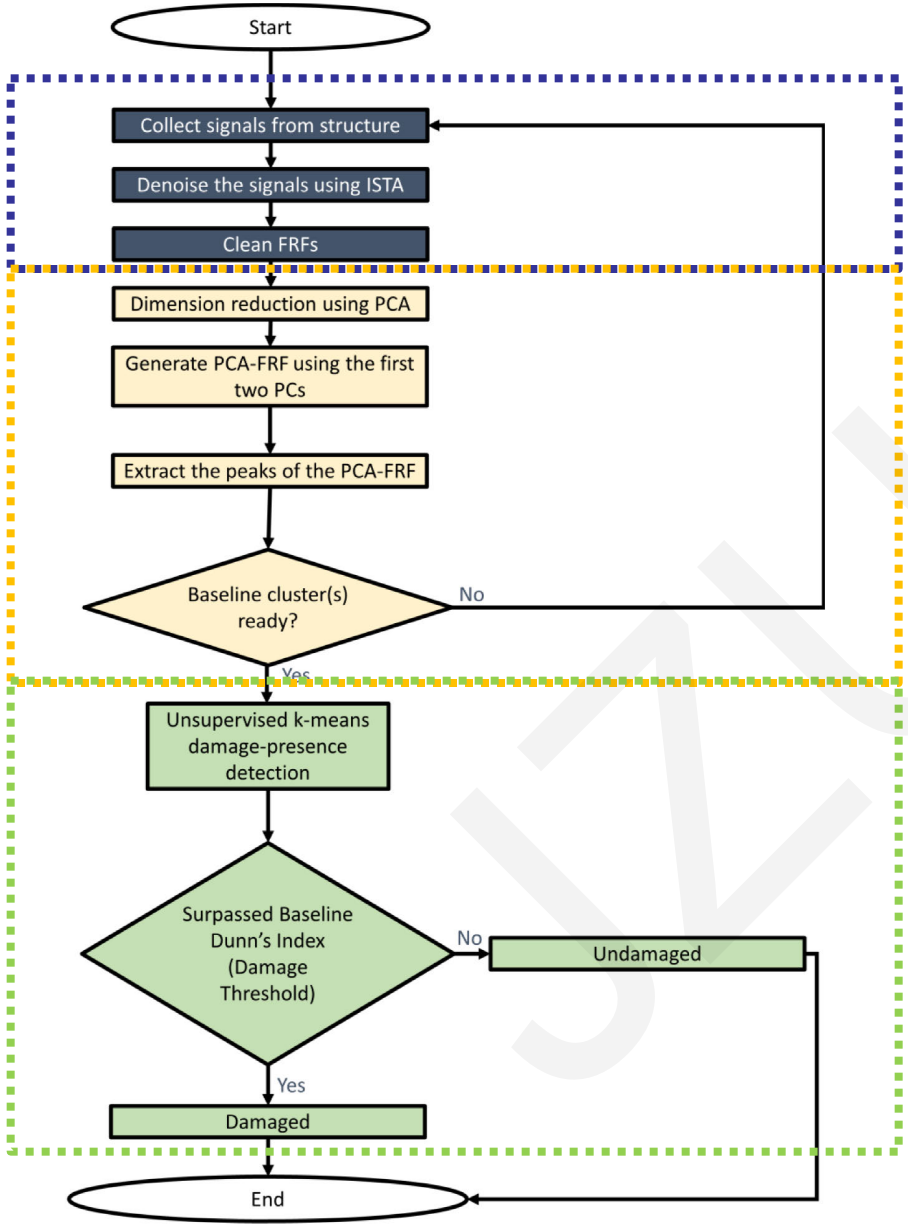
■ Conventional modal analysis method would require shutdown conditions or compromise accuracy of modal data.

Solution

■ **Principal Component Analysis-FRF (PCA-FRF)** as the **damage-sensitive** compressed modal feature for unsupervised damage detection.

■ **Impact-Synchronous Modal Analysis (ISMA)** to enable **real-time operational** structural damage detection using **static-like modal data**.

The Proposed Damage Detection Scheme



1. Signal Denoising using ISMA

2. Dimension Reduction & Feature Extraction using PCA

3. Damage detection using Unsupervised K-Means

Denoising Feature of ISMA on FRFs: Method

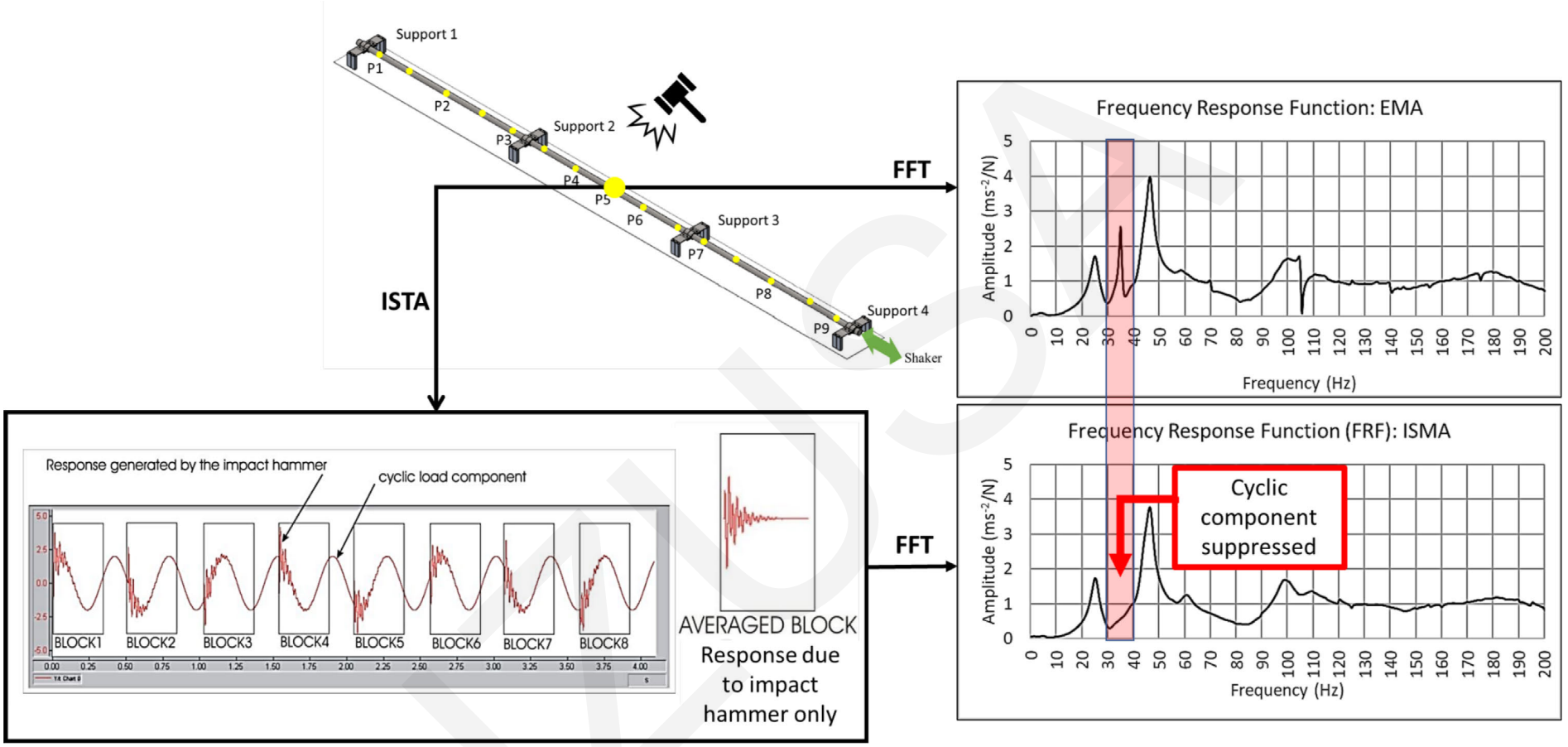


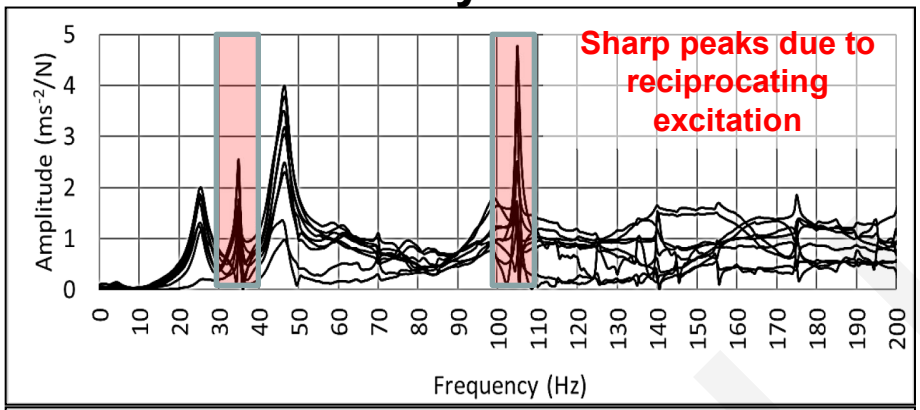
Fig. 1. Elimination of the running speed with ISTA and the generated FRF, adapted from (Bin Zahid, et al., 2020).

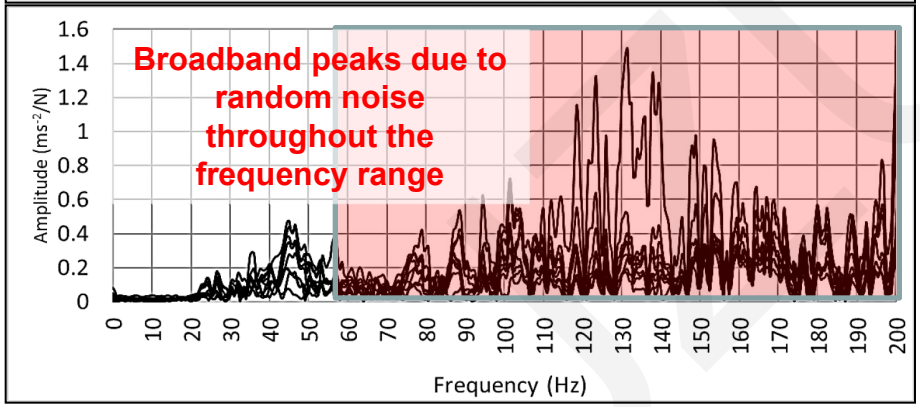
Elimination of running speed in time domain to generate clean FRFs using ISMA.

Denoising Feature of ISMA on FRFs: Results

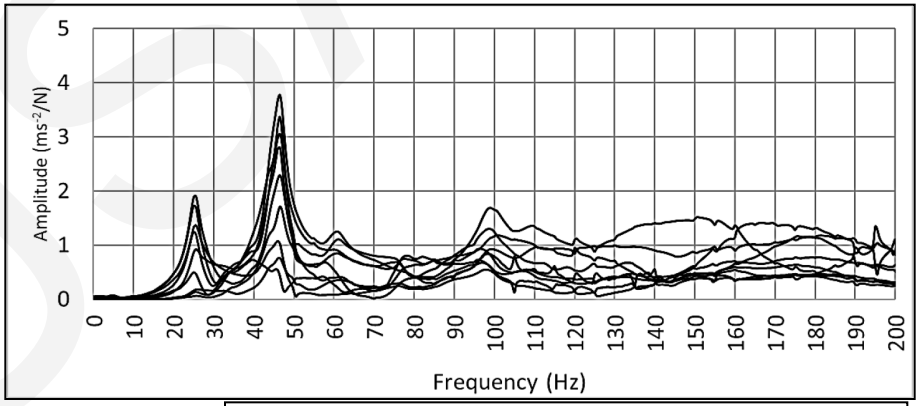
- **Comparison of FRFs of EMA and ISMA at noisy conditions**

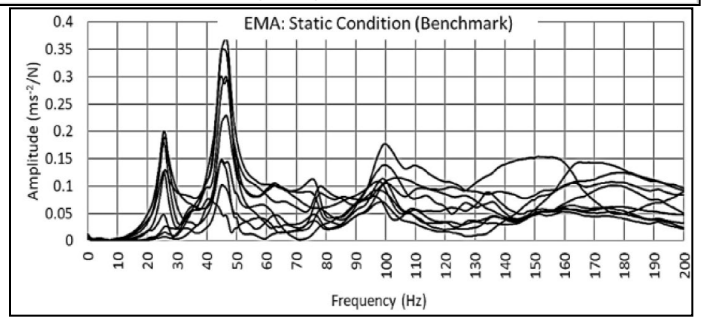
EMA at noisy conditions





ISMA at noisy conditions

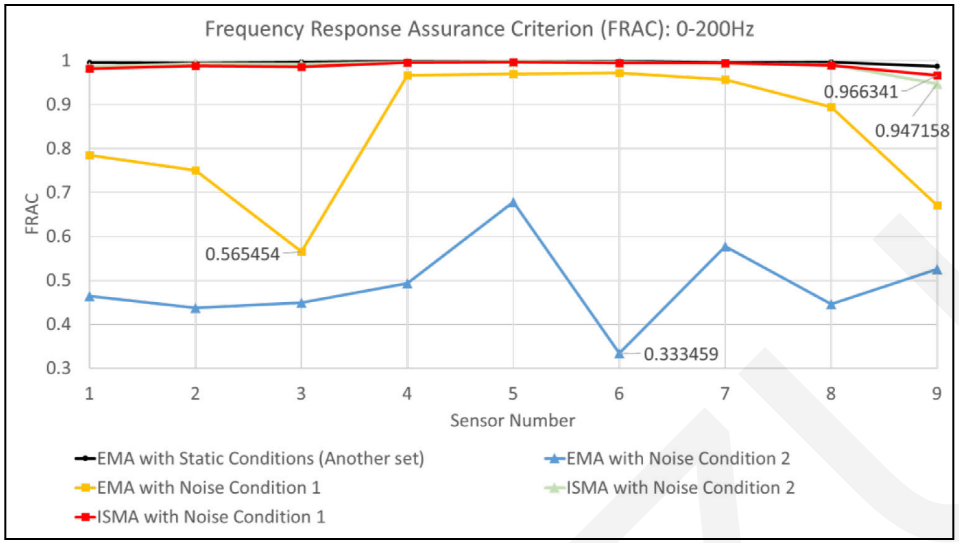


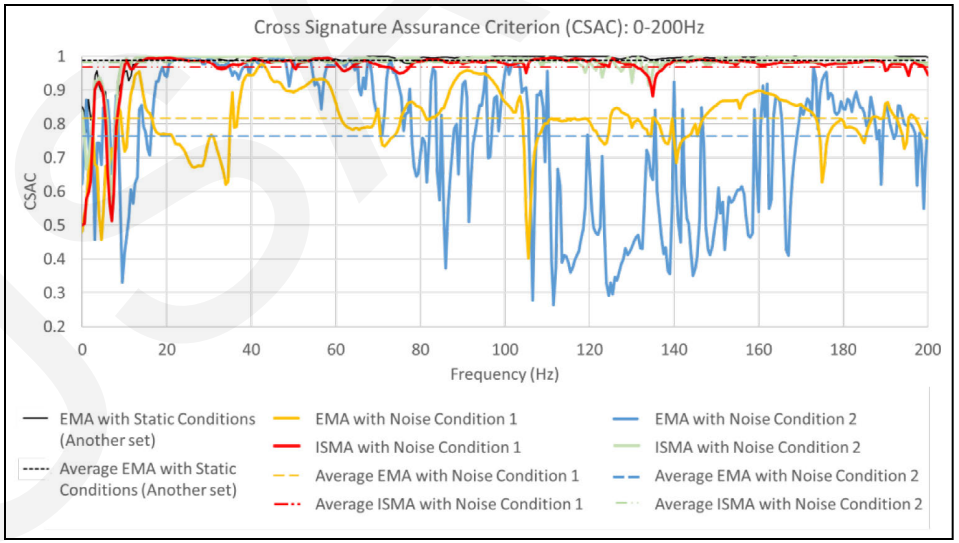


ISMA produces clean static-like FRFs with only the structural resonance peaks at noisy conditions.

Denoising Feature of ISMA on FRFs: Results

- **Correlation scores: EMA with static condition as the reference**

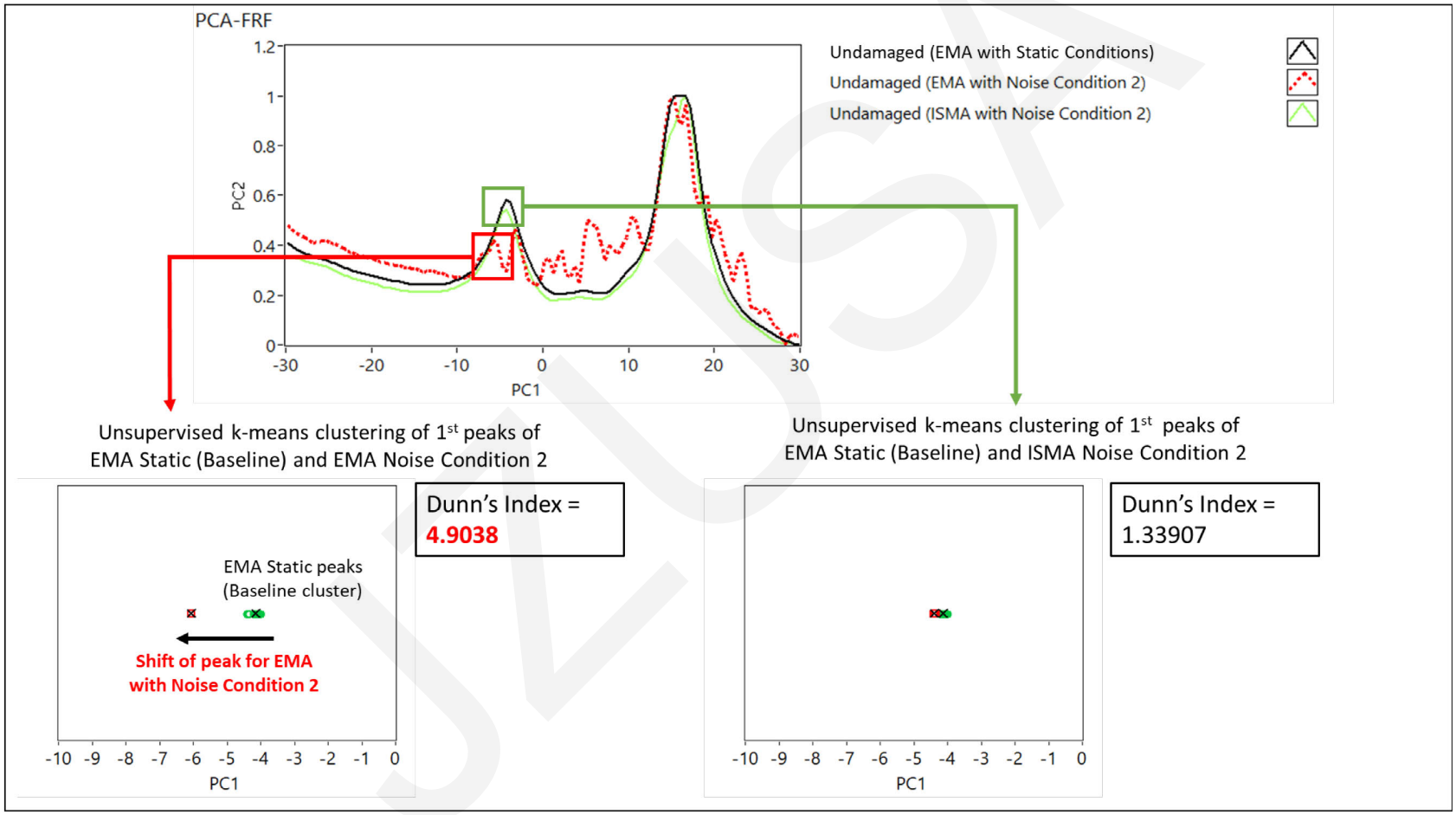




ISMA produces FRFs that have correlation scores (FRAC & CSAC) of greater than 0.9 (red line in graphs) when compared to benchmark FRFs.

Noise Robustness of ISMA in Unsupervised Damage Detection: Results

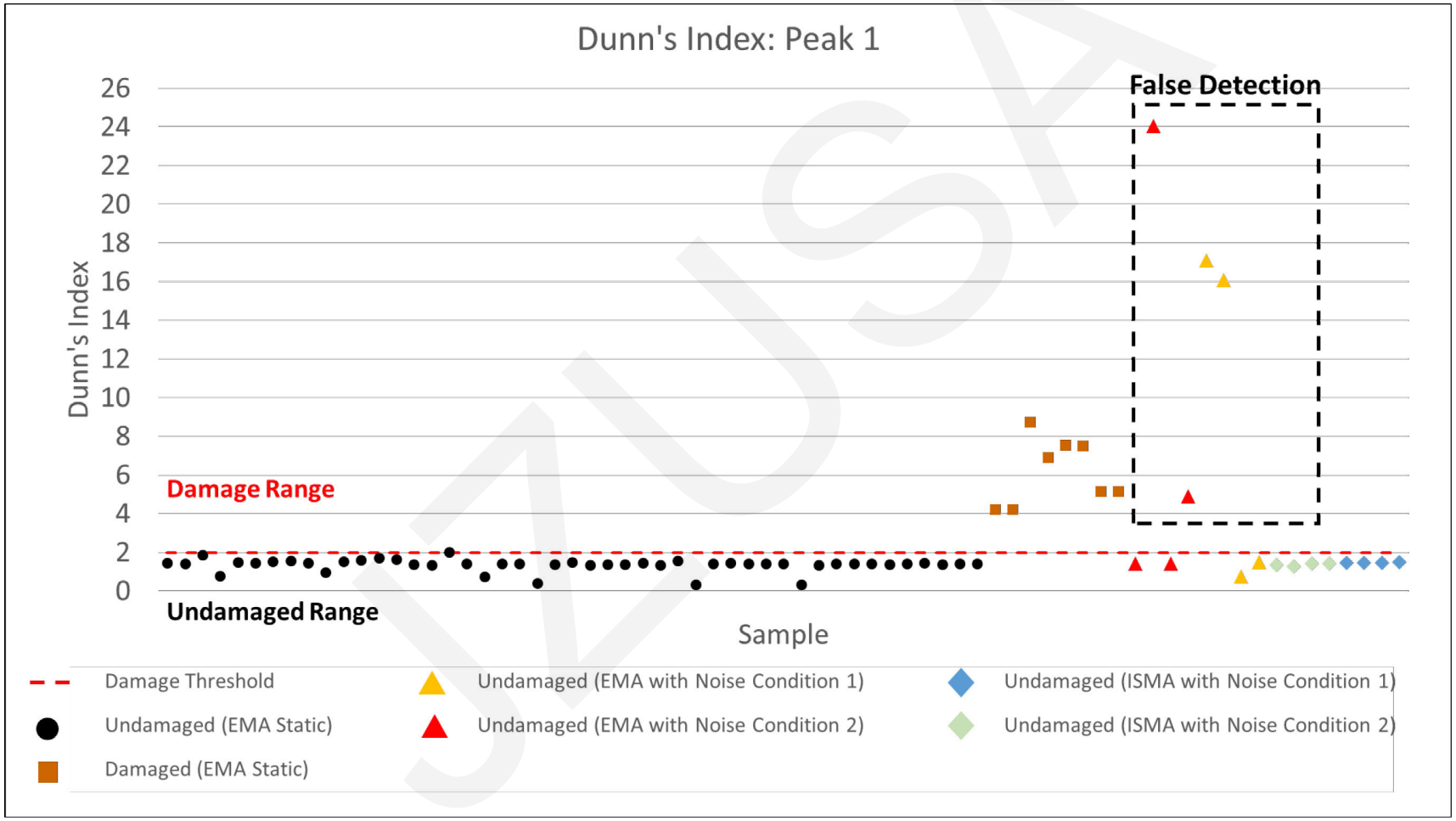
■ Unsupervised damage detection using PCA-FRF peak



ISMA eliminates peaks due to noise in FRFs, resulting in no false shift due to damage in the PCA-FRF peak.

Noise Robustness of ISMA in Unsupervised Damage Detection: Results

Unsupervised damage detection results



No false alarms when ISMA was performed at noisy conditions.

Conclusions

- ISMA produces static-like FRFs with correlation scores of greater than 0.9. The noise and cyclic loads are removed, thus ISMA is effective in signal denoising.
- No false alarms were detected when the peaks of the PCA-FRF of ISMA were used in the unsupervised damage detection method. Thus, ISMA is noise robust in an unsupervised method.