DAMAGE IDENTIFICATION OF TRUSS STRUCTURES USING MODAL ANALYSIS AND NUMERICAL OPTIMIZATION

Bhavika Dhyani[1] and Vagelis Plevris[1]
[1]College of Engineering, Qatar University, Doha, Qatar

Graduate Students, Energy and Environment

Abstract

Truss structures play a pivotal role in civil engineering, and their safety and integrity are of paramount importance. Structural damage, whether caused by external factors or long-term wear, poses a substantial risk to these systems. This thesis addresses the need for efficient and precise methods to detect, locate, and assess damage in truss structures. The study commences with a rigorous examination of modal analysis, a fundamental tool in structural dynamics, enabling the characterization of a structure's dynamic behavior through natural frequencies and mode shapes. Then it delves into the integration of numerical optimization techniques, leveraging mathematical algorithms to enhance the accuracy and reliability of damage identification. Numerical optimization not only refines the identification process but also enables the quantification of damage severity and localization within the structure. Three optimizers are employed and compared with each other: GA, PSO and SQP, while several modal correlation criteria are used as objective functions to be minimized. By combining modal analysis with numerical optimization, a robust and effective methodology for damage identification in truss structures is established. The methodology offers a valuable toolset for safeguarding these critical engineering systems, enhancing their reliability, and ultimately facilitating the sustainable development of structures and infrastructures.

Introduction

- Truss structures, characterized by their simplicity, efficiency, and versatility, have been instrumental in shaping the modern world's architectural and engineering landscape.
- Truss structures, like all engineered systems, are susceptible to damage due to a multitude of factors, including environmental forces, wear and tear, and unforeseen events.
- Detecting and evaluating such damage in truss structures, while it is still in its incipient stages, is imperative to prevent catastrophic failures, reduce maintenance costs, and extend the lifespan of these structures.
- The thesis embarks on a rigorous exploration of a critical facet of structural engineering—the identification of damage in truss structures.
- It endeavors to leverage two powerful tools, Modal Analysis and Numerical Optimization, to address the complexities of damage detection and assessment.
- By integrating these methodologies, this thesis seeks to not only enhance our understanding of structural dynamics but also to develop a robust framework for the identification of damage within truss systems.
- The damage should be detected, localized, measured and then these can be used to predict the health of the structure. This can be shown schematically in the form of four levels:

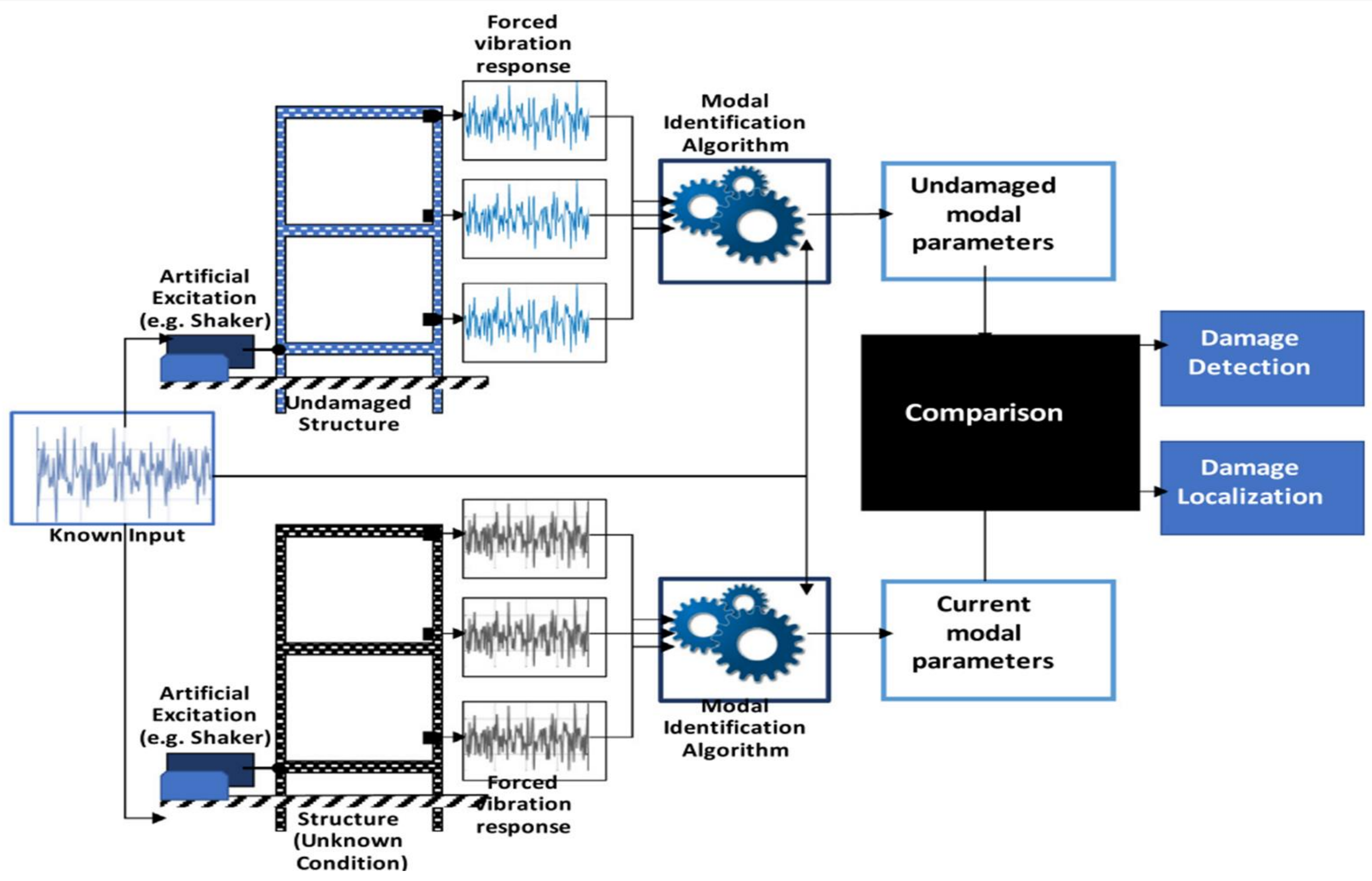
Objectives

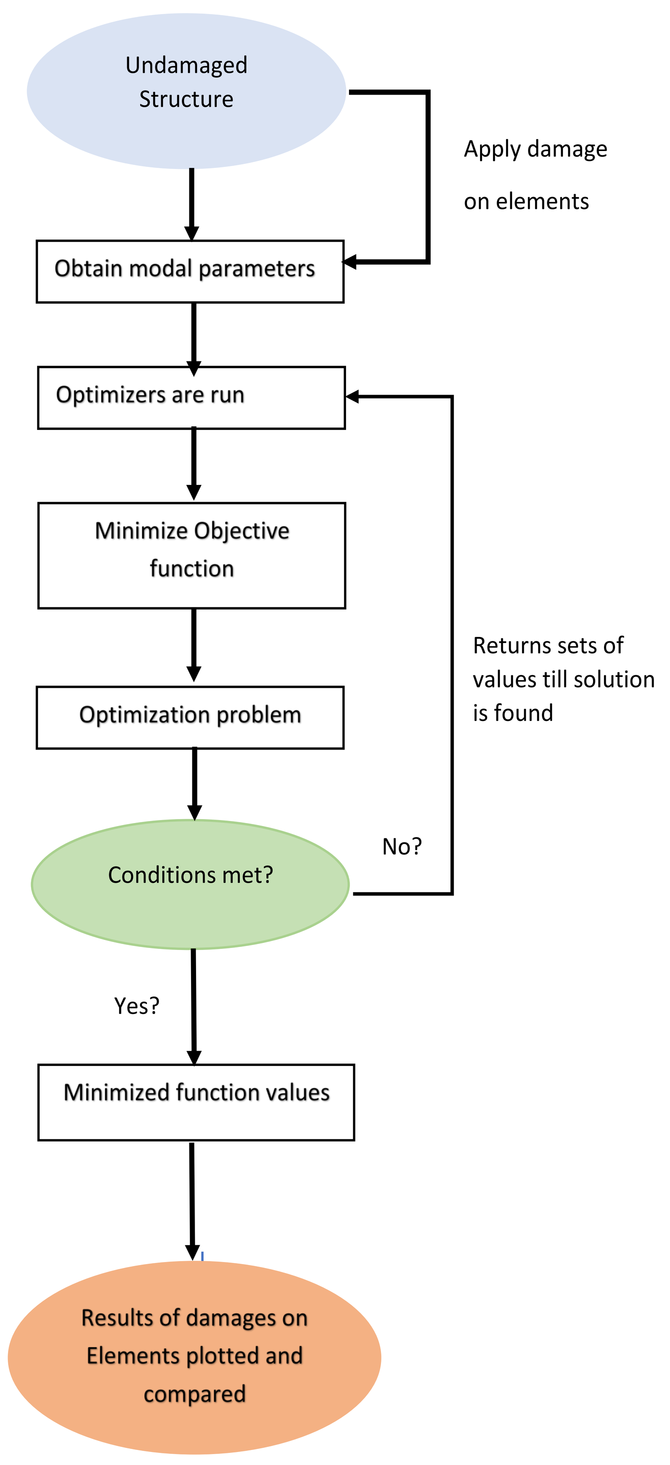
- To detect, locate and quantify the severity of the damage in a truss structure, based on modal characteristics such as natural frequencies and mode shapes.
- To compare different optimization algorithms and their effectiveness in handling this complex problem.
- To compare different modal correlation criteria and identify which one can be used most effectively.
- To examine whether reliable results can be achieved even if noise is present in the available modal data.

Abbreviations:

GA: Genetic Algorithm, **PSO**: Particle Swarm Optimization,
SQP : Sequential Quadratic Programming

Methodology





Criteria used:

- **MTMAC**
(Modified Total Modal Assurance Criterion)
- **COMAC**
(Coordinate Modal Assurance Criterion)
- **MACFLEX**
(Flexural Modal Assurance Criterion)
- **Combined**
- (MTMAC and MACFLEX)

Results & Discussion

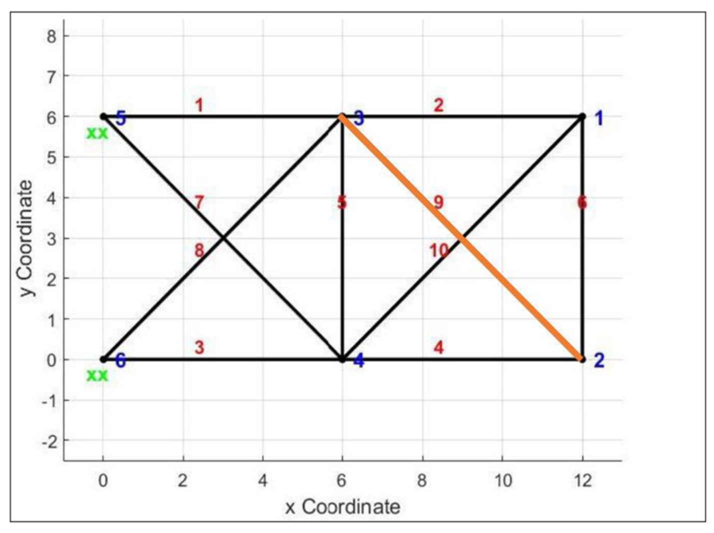


Figure 1. Case 1: Element 9 has 20 % damage.

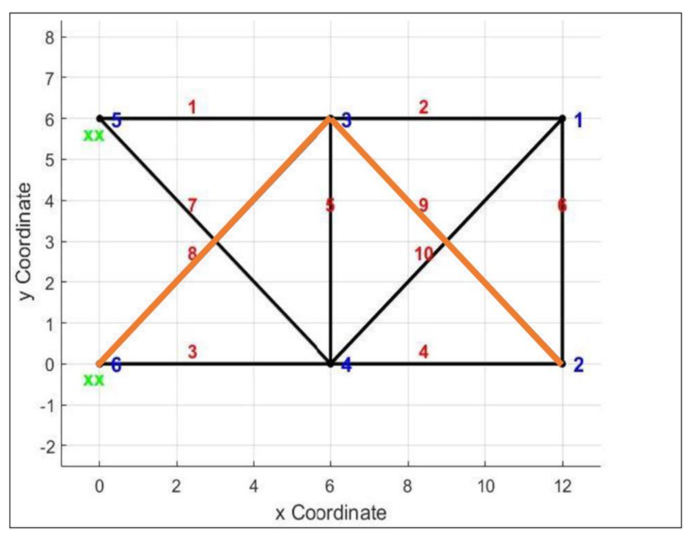


Figure 2. Case 2: Element 8 and 9 have 30% and 20% damage, respectively.

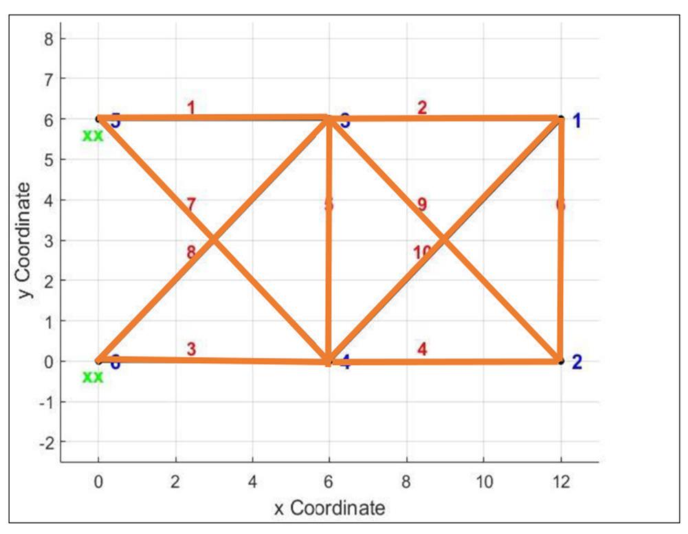


Figure 3. Case 3: All elements have 20% damage (uniform damage).

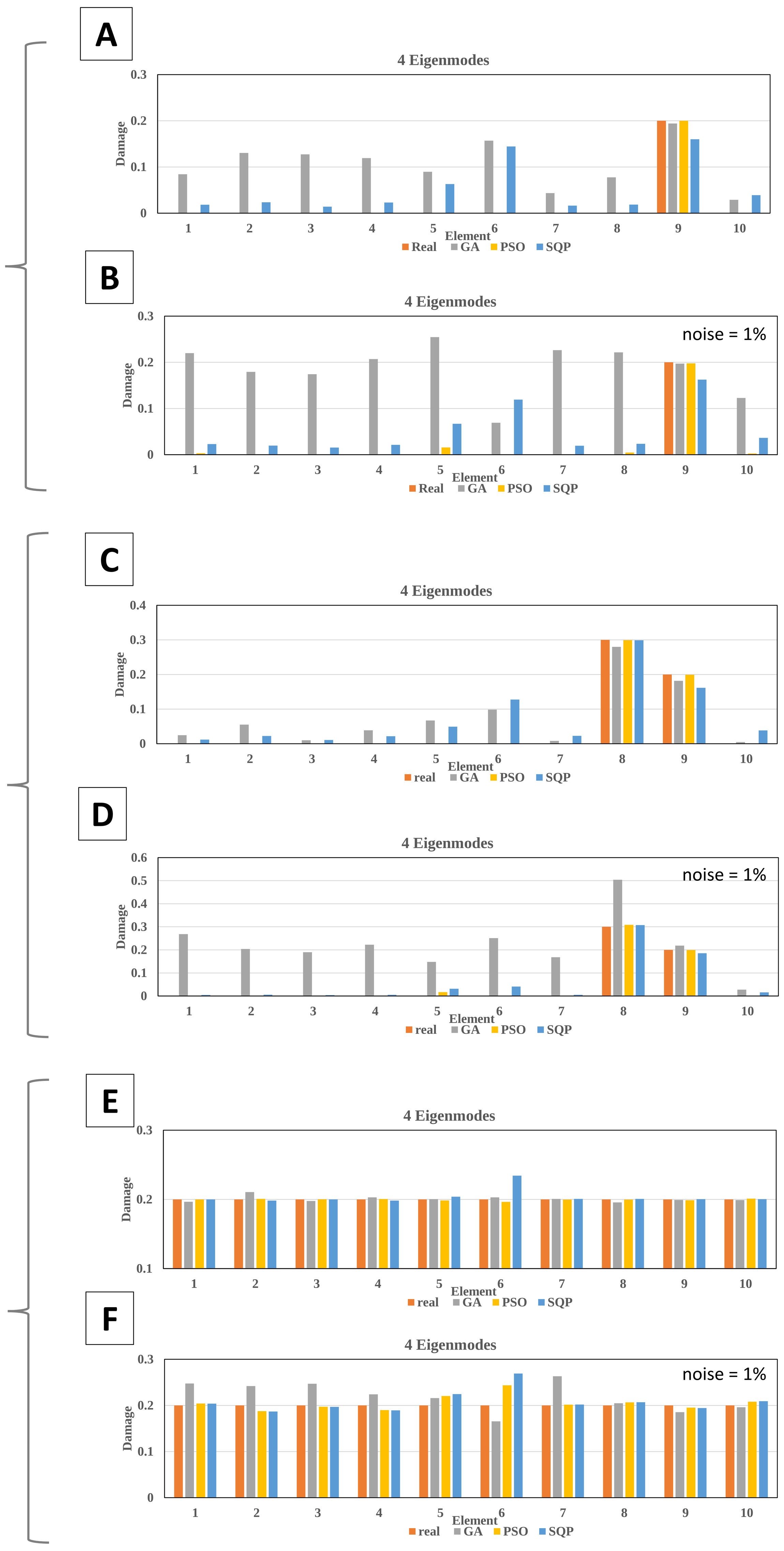


Figure 4. Comparison of the optimizers for different damage scenarios where A, C , E have no noise and B, D, F have noise 1%.

Conclusions

- A small number of dynamic properties can help detect damage and its severity.
- The PSO algorithm is extremely effective and displayed good performance.
- MACFLEX, MTMAC and the combined criteria work best for most optimizers.
- The method can detect damage even when noise is present in the data.
- The method is simple, quick and reliable. It can empower engineers to make informed decisions regarding repair and maintenance, ultimately ensuring the continued safety and longevity of truss-based infrastructure.

Future Research Directions

- Use additional available modern optimizers, such as Simulated Annealing (SA), Differential Evolution (DE), and others.
- Integrate machine learning and AI algorithms to enhance the processing and interpretation of structural modal data, enabling automated and more robust damage detection algorithms.

References

[1] *Georgioudakis, M. and V. Plevris (2016). "Investigation of the performance of various modal correlation criteria in structural damage identification", VII European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2016), pp. 5626-5645, Crete Island, Greece, 5-10 June 2016 (DOI: 10.7712/100016.2207.11846).*
[2] *Alkayem, N. F., et al. (2022). "A new self-adaptive quasi-oppositional stochastic fractal search for the inverse problem of structural damage assessment", Alexandria Engineering Journal 61(3): pp. 1922-1936 (DOI: 10.1016/j.aej.2021.06.094).*