Material Degradation and Defect Assessment in Beam Structures Using Mechanical Responses

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Abstract

Structural Health Monitoring (SHM) plays a vital role in the early detection of defects in engineering structures, preventing catastrophic failures and reducing maintenance costs. This study proposes a damage assessment approach based on normalized natural frequency ratios obtained from intact and damaged finite element (FE) beam models. The normalized frequency ratios are used to identify defect locations, while damage severity is estimated by comparing the dynamic responses of healthy and damaged structures. Several defect scenarios with varying locations and severities are investigated to evaluate the proposed method. The numerical results demonstrate that the approach accurately localizes defects and estimates damage magnitude, providing a simple, efficient, and reliable technique for structural defect assessment in beam structures.

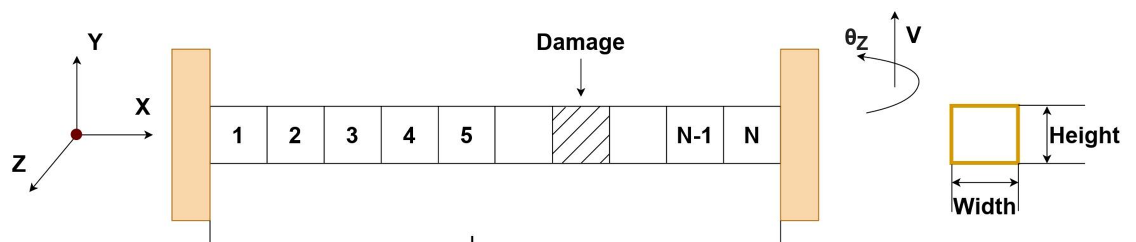
Context

Structural defects reduce the safety and reliability of engineering structures. This study presents a structural health monitoring approach using dynamic parameters. Normalized natural frequency ratios are used for defect localization and severity estimation.

Problem Statement

Existing defect detection methods are often costly and computationally intensive. Accurate localization and quantification of structural defects remain challenging. A simple, reliable, and efficient damage assessment approach is therefore needed.

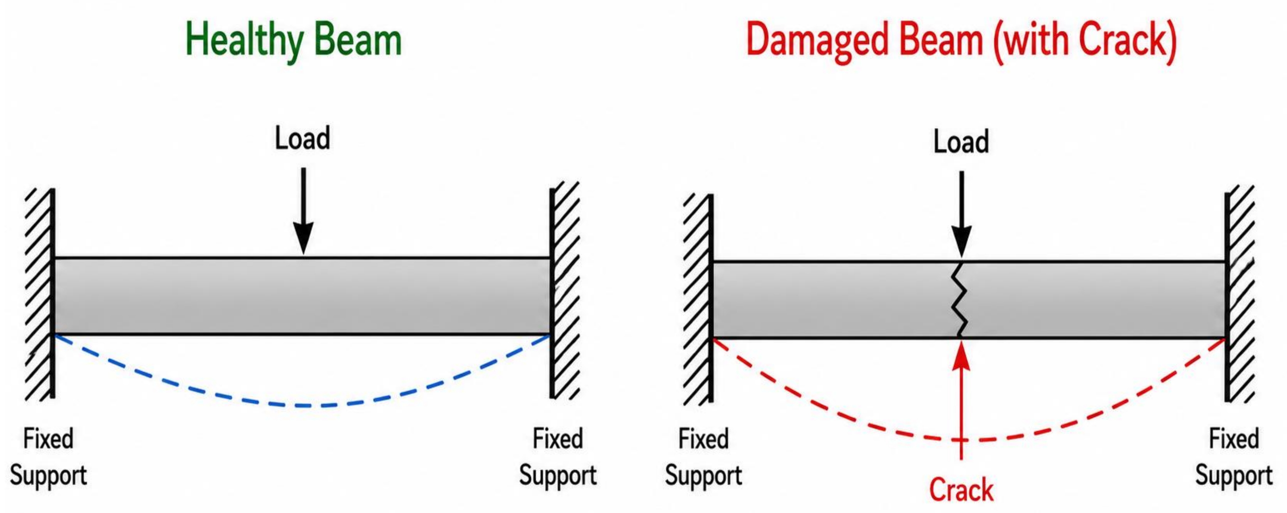
Fixed-fixed beam example



=> *Frequencies f and mode shapes ϕ*

Beam Properties

Material-Aluminium
Length = 1500 mm
Width =50 mm
Thickness = 5 mm
Young's modulus = 69 GPa
Number of FE Elements (N) = 50



Methodology

1. **Intact FE Beam Model** (Develop finite element model of healthy beam)
2. **Modal Analysis (Intact)** (Obtain natural frequencies of intact beam)
3. **Introduce Defect** (Introduce crack at different locations and severities)
4. **Modal Analysis (Damaged)** (Obtain natural frequencies of damaged beam)
5. **Normalize Frequencies** (Compute normalized frequency ratio: f_i / f_d)
6. **Damage Localization** (Identify damage location using frequency ratio variation)
7. **Damage Severity Estimation** (Estimate damage severity from frequency ratio)
8. **Validation & Results** (Validate method using various scenarios and evaluate performance)

1. Normalized Natural Frequency Ratio

$$R_i = \frac{f_{d,i}}{f_{h,i}}$$

where:
R_i = normalized natural frequency ratio
$f_{h,i}$ = natural frequency of the healthy beam (mode i)
$f_{d,i}$ = natural frequency of the damaged beam (mode i)

2. Frequency Change Ratio

$$\Delta f_i = \frac{f_{h,i} - f_{d,i}}{f_{h,i}}$$

where:
Δf_i = relative change in natural frequency due to damage (mode i)

3. Damage Severity

$$D(\%) = \frac{f_{h,i} - f_{d,i}}{f_{h,i}} \times 100$$

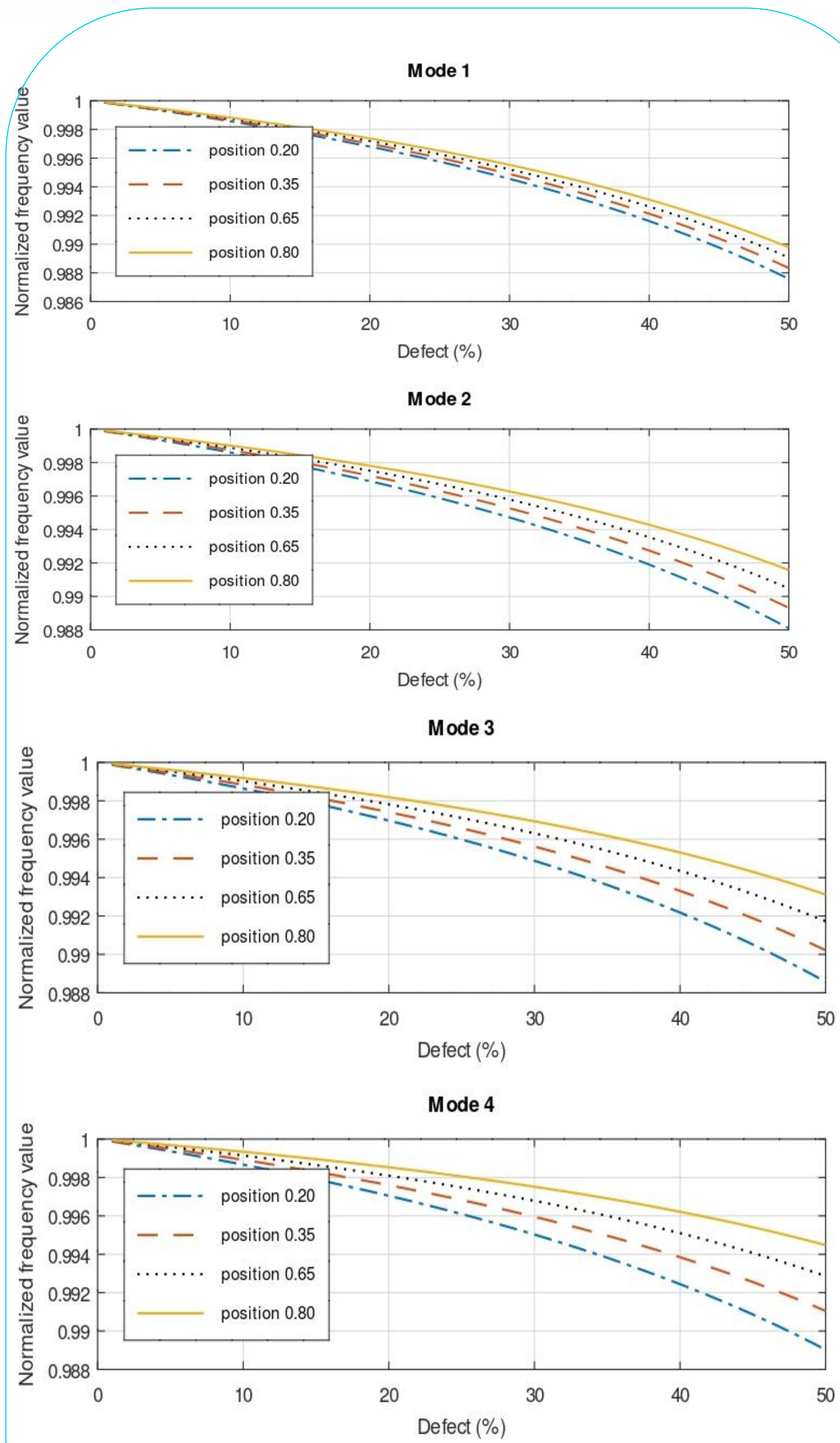
where:
$D(\%)$ = estimated damage severity in percentage (mode i)

4. Damage Localization

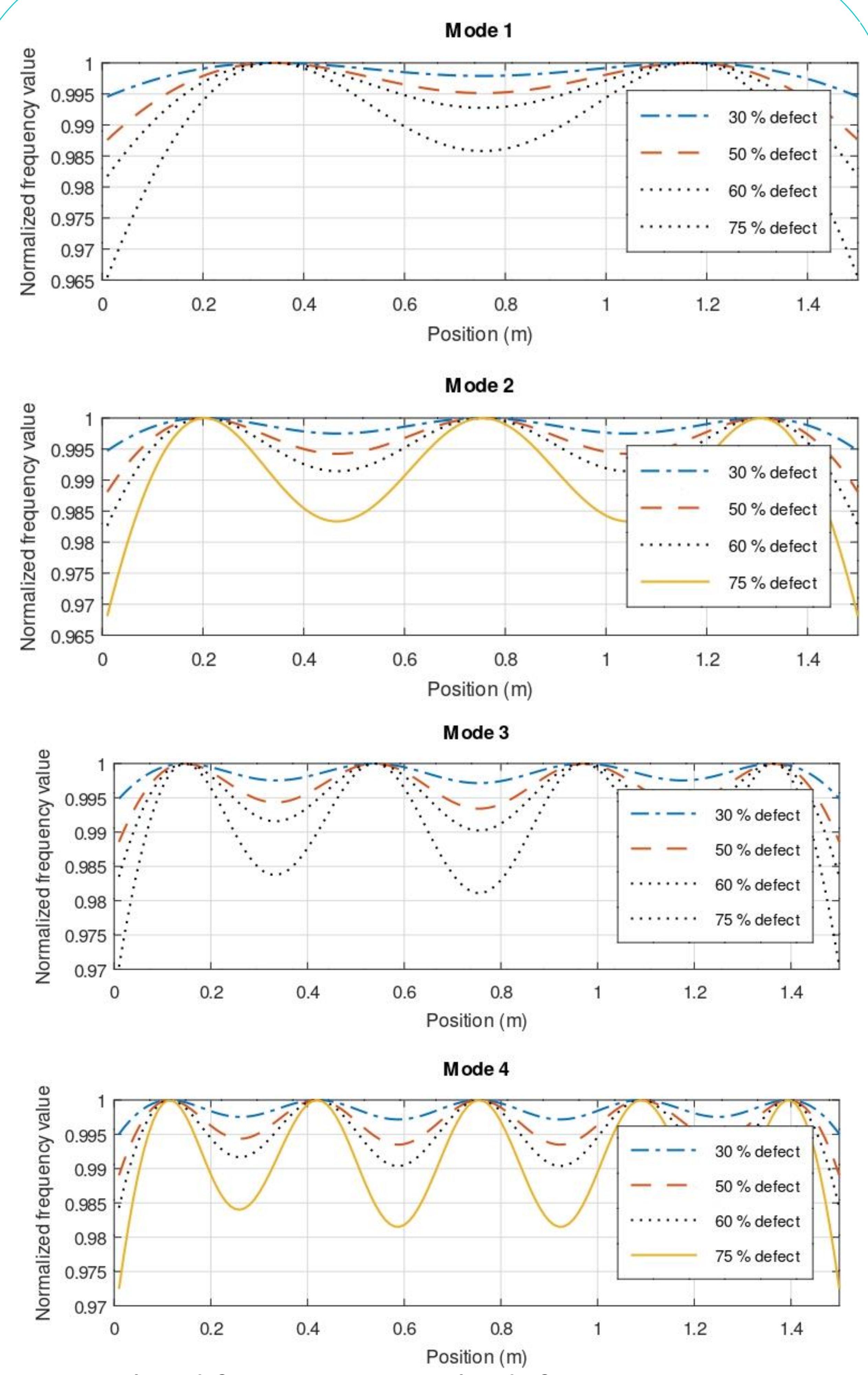
$$L = f(R_i)$$

where:
L = damage location along the beam (identified using the variation of R_i)
R_i = normalized natural frequency ratio

Results



Normalized frequency variation with defect depth: Mode1 , Mode 2, Mode 3, Mode 4



Normalized frequencies with. defect position : Mode1, Mode 2, Mode 3, Mode 4 .

Conclusion: The proposed technique provides a reliable tool for structural health monitoring and can be extended to more complex engineering structures.

Reference: Farrar, C. R., Doebling, S. W., & Nix, D. A. (2001). *A Review of Structural Health Monitoring Literature: 1996–2001*. Los Alamos National Laboratory Report, LA-13976-MS.