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Lecture 9

Module 2

Vibration-based methods of SHM – I

– Damage identification

Comparison

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Fundamental idea of vibration-based monitoring

- to detect damage based on the fact that

"damage-induced vibration changes structural properties like mass, stiffness, damping.

detecting these changes in comparison to an undamaged model is useful to detect damage

- what are these parameters, which are compared

  - frequency
  - mode shape
  - modal damping

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for example,

- reduction in stiffness inturits formation of cracks
- Therefore, damage can be identified by change in stiffness characteristics of the structure

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(1) Natural frequency - based methods

- These methods use (ω_n) as the basic feature for damage identification
  - Identification of damage is different from location of damage

- It is a good choice
  - natural frequencies of a system can be readily measured @ few accessible points in the structure
  - These are less-contaminated by Noise data

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a) MDLAC - Multiple Damage Location Assurance Criterion

- This is a statistical correlation between analytical prediction of change in frequency and the measured frequency

MDLAC is actually a function of damage extent vector (δ_D)

$$MDLAC = fn(\delta_D)$$

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$$MDLAC(\{\delta_D\}) = \frac{\left| \{\Delta f\}^T \; \delta_f(\{\delta_D\}) \right|^2}{\left(\{\Delta f\}^T \{\Delta f\} \right) \cdot \left(\{\delta_f(\{\delta_D\})\}^T \{\delta_f(\{\delta_D\})\} \right)} \quad \text{— (1)}$$

where δ_f - analytical prediction of frequency change

Δf - measured frequency change

MDLAC provides a good prediction of both

- location of damage
- size of damage (extent of damage)

@ one or more sites.

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(b) SDI (Single Damage Indicator)

- It is useful to locate and Quantify the damage in flexural members.
- It is good to locate & Quantify Cracks in beams.
- This method uses change in it to detect the damage
- Fractional change in Modal Energy is related to the fractional change in frequency, which has occurred due to damage

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SDI is used to indicate damage location

$$SDI_j = \left[\sum_{i=1}^{NM} \mathcal{C}_{ij}^2 \right]^{-1/2} \qquad (2)$$

where $\mathcal{C}_{ij}$ = Error index

= used to represent localization Error for i^{th} mode in j^{th} location

$$\mathcal{C}_{ij} = \frac{Z_i}{\sum_{k=1}^{NM} Z_k} - \frac{F_{ij}}{\sum_{k=1}^{NM} F_{kj}} \qquad (3)$$

where Z_i is the fractional change in i^{th} Eigenvalue due to damage

This is given by

$$Z_i = \frac{\delta\omega_i^2}{\omega_i^2} \qquad \text{(4)}$$

Further, sensitivity of the i^{th} modal stiffness to j^{th} element is given by

$$F_{ij} = \frac{k_{ij}}{k_i} \qquad \text{(5)}$$

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(c) SCCM (Spectral Centre Correction Method)

This method is useful to detect damage based on auxillary mass spatial probing.

- SCCM correlates highly accurate natural frequency value based on the auxillary mass location to detect damage

- limitations:
  - It is very difficult to compute natural frequency with high accuracy
  - Hence, applying correction based on its correlation to auxillary mass is difficult & complex

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Limitations of frequency-based methods of damage detection

I

- Most of the frequency-based methods are Model-dependent
- Damage identification strongly depends on Euler-Bernoulli Beam Theory
  - Crack formation is modelled as rotational spring

(i) Euler-Bernoulli theory overpredicts natural frequency in short beams and high-frequency bending modes

(ii) Modeling crack as rotational spring is unsuitable for higher modes of vibration
  - not suitable for deep/wide cracks

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frequency-based methods are more suitable for slender structures only!

II. Limitations related to frequency changes

- frequency changes caused by presence of damage are lesser in comparison to those caused by other factors like Environmental & operational conditions

studies show that frequency changes, caused by Environmental and operational conditions are usually in the range 5-10%.

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Therefore, frequency changes caused by damage should be to this scale, to make them noticable (atleast 5% change should be noted in frequency changes, so that they can be recognized)

- Results in 5% change - is possible only when the damage is severe/deep in nature

- Frequency-based methods can be used to detect damage only when the damage is significant

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(11) Damage locations proposed by these methods are generally ill-conditioned

- Damage with same severity occurring in symmetric locations will result in identical frequency changes.

Damages with different severity, occurring in different locations (which are not symmetric) can also cause identical frequency changes.

- This has been verified in few cases of measurements (Wu)

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frequency-based methods of damage detection

are not effective to detect/locate multiple cracks

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Summary

- Comparison of vibration-based methods & Damage detection

(1) Natural frequency-based methods

MDLAC
SDI
SCCM

(3) serious limitations

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