Module 2

Lecture 10

Comparison of Damage detection methods – II

- Natural frequency - based methods - for damage detection

- Limitations of these methods
  - They use Euler-Bernoulli Beam theory to indicate the damage
  - It overpredicts natural frequency in short-beams and high frequency bending modes

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II Mode shape-based methods

Basic objective

These methods use mode shape and their derivates for damage detection

- Mode shapes depict relative position of mass when the structural system is vibrating @ a specific frequency
  - They are mass sensitive
    - any change in mass will be reflected in the mode shape
    - This characteristic is used for damage detection

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(ii) Modes shapes are very illustrative & interesting to use in case of multiple damage detection

- They are highly sensitive to presence of multiple damages

(iii) Mode shapes are less sensitive to environmental effects like temperature variation etc

in comparison to the variations/ sensitivity of natural frequencies

Limitations

(1) To measure modeshape, series of sensors are to be placed in the lumped mass points (one @ each mass point)
- they are expensive

(2) Mode shapes are more prone to contamination by presence of noise generated by machine vibration, electrical appliances etc
- They may also create a false damage location

Change in mode shape - is a common phenomena used to detect damage

- Change in mode shape between undamaged and damaged members can be used to detect damage

- Mode shapes can be obtained either experimentally or numerically

- Mode shapes are sensitive to damages, occurred on critical areas for example, midspan of a simply supported beam

- For accurate localization of the damage, are generally signal pattern recognition - additional processing

- ∵ more sensors are required with higher sensitivity, this application in large structures is highly limited

(3) Mode shape analysis with Modern Signal processing

Since change in mode shape b/w undamaged and damaged member is required for damage detection, it is important that mode shape in undamaged section should be evaluated with higher accuracy numerical model.

- Numerical models with higher accuracy are also computationally expensive

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When mode shape analysis can be carried out using signal processing, then there is no need for numerical model.

Mode shapes, which are estimated/obtained from the experimental investigation can be used to detect damage

- No detailed Numerical model is essential

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Basic assumption is this method is that

- Mode shape data of an undamaged structural system contains only low-frequency signal. in the spatial domain

  presence of high-frequency signal is an indicator of presence of damage in the structure

- high-frequency signals should be filtered out from the mode shape data - Modern signal processing

(2) methods : (i) Fractal dimension method (FD)

(ii) Wavelet Transform method

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- Both these methods cannot be used for damage Quantification

- They can be used only for damage detection.

FD of a mode shape curve is given by:

$$FD = \frac{\log_{10}(n)}{\log_{10}(d/L) + \log_{10}(n)} \qquad (1)$$

where n - # of steps in the mode shape curve

d - distance between 1st point of sequence (P_1) and its point of sequence (P_i), which provides the farthest distance

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L = total length of the curve

$$= \sum_{i=1}^{n-1} dist(P_i, P_{i+1})$$

$$d = maxdist(P, P_i)$$

Peak of FD curve can locate the damage and also its size ✓

- Inferred by showing up of the local irregularities of fundamental mode
  - generally introduced/caused by presence of damage

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If higher modes are to be included in the analysis,
then Fractal Dimension method (FD) is replaced
by Generalized Fractal method (GF.M)
which is an improvement by a scale factor (S)

$$GFD = \frac{\log_{10}(n)}{\log_{10}(d_s/L_s) + \log_{10}(n)}$$

$$d_s = \max_{1 \le j \le M} \sqrt{(y_{i+j} - y_i)^2 + S^2 (x_{j+i} - x_i)^2}$$

$$L_s = \sum_{j=1}^{M} \sqrt{(y_{i+j} - y_{i+j-1})^2 + S^2 (x_{i+j} - x_{i+j-1})^2}$$

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Wavelet transform method

- closely examines the signal of mode shape with a multiple scale
  - To provide max details and approximation about the mode shape curve itself

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(4) Using <u>Mode shape curvature</u> (MSC) in damage detection

- Mode shape curvature is 2^{nd} derivative of the mode shape.
- They indicate high sensitivity to the presence of damage
- curvature of a mode shape can be approximated using central difference technique as:

$$k_i = \frac{(\omega_{i+1} + \omega_{i-1} - 2\omega_i)}{h^2}$$

where ω is the modal displacement point
h is the spacing of the sensor, used to obtain mode shape

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change in curvature of mode shape is a good indicator of damage

- It is useful to identify both
  1) presence of damage
  2) location of damage

But, in higher modes, MSC shows several peaks

- This is a false indicator of damage

curvature of lower mode shapes (fundamental mode shape) is very useful in damage identification

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V Modal Strain Energy Method (MSE)

I - change of natural frequency - damage detection

II - change in mode shape

III - Analysis of mode shape - Modern signal processing

IV - Mode shape curvature

V - MSE method

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Fractional change is Modal strain Energy is also a good indicator of damage detection

For bending elements (beams & plates), Modal strain Energy can be directly related to mode shape curvature

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Algorithm	Type	parameters reqd	Basic assumption	Damage Indicator
(1) SDI	Model-based	natural frequency should be measured & compared b/w damaged & undamaged system	single damage	This method works well @ the element level
(2) GFD	Response-based This considers only the response of a damaged state	mode shape of damaged state should be measured and supplied as Input, (ω_n)		DI is confined to the sensor location

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MSC	Response-based method	measurement of mode shape curvature of both damaged and undamaged member		Damage indication is confined to sensor locations

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Summary

- All methods are effective for small sensor-spacing conditions
- They are capable of locating single damage
  - except – MSC – which can locate multiple damages
- Fundamental mode shape may not be always the most effective mode for damage detection
  - Even higher modes may also become sensitive for damages
- Natural frequency ratio b/w damaged and undamaged member can be a good indicator for damage presence, in certain modes

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- Mode shape curvature method is more robust in case measurements are disturbed by presence of external noise
  - m/c vibration
  - Electrical signals

Ref

Wei Fan, Pizhong Qiao. 2011. Vibration-based damage identification methods: A review and comparative study, Structural Health Monitoring, SAGE publications, 10(1): 83-110.