

**Structural Health Monitoring (SHM)**  
**Prof. Srinivasan Chandrasekaran**  
**Department of Ocean Engineering**  
**Indian Institute of Technology, Madras**

**Lecture – 26**  
**Vibration based health monitoring scheme – Part 2**

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Damage detection by frequency based method

FBDD - Frequency-based damage detection

A single damage index, for  $j^{\text{th}}$  member of any structural system is given by:

$$DI_j = \left[ \sum_{i=1}^{NM} e_{ij}^2 \right]^{-1/2} \quad (7)$$

where  $DI$  - damage index (indicator) @ the  $j^{\text{th}}$  element of the structure  
 $NM$  - # of vibration modes considered for the analysis  
 $e_{ij}^2$  - localization error for  $i^{\text{th}}$  mode, in the  $j^{\text{th}}$  element of the structural system

Alternatively, one can also use frequency band method for Damage Detection called FBDD, Frequency based damage detection. A single Damage Index for  $j$  th member of any structural system is given by damage index of  $j$  th member is summation of  $i$  equals 1 to  $NM$ , the number of vibration modes square  $i j$  minus half.

Where  $DI$  is the damage index or indicator at the  $j$  th element of the structure;  $NM$  indicates number of vibration modes considered for the analysis,  $e_{ij}^2$  is actually the localization error for  $i$  th mode in the  $j$  th element of the system.

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which is given by:

$$e_{ij} = \frac{Z_i}{\sum_{k=1}^{NM} Z_k} - \frac{F_{ij}}{\sum_{k=1}^{NM} F_{kj}} \quad (8)$$

$$Z_i = \frac{\delta \omega_i^2}{\omega_i^2} \quad (9)$$

Where  $Z_i$  indicates fractional change which is caused by the damage in the  $i^{\text{th}}$  eigenvalue.

$$\delta \omega_i^2 = \omega_i^{*2} - \omega_i^2 \quad (10)$$

Which can be given by  $e_{ij}$  is  $Z_i$  summation  $k$  equals 1 to  $N \times M$   $Z_k$  minus  $F_{ij}$  by summation  $k$  equals to 1 to  $N \times M$   $F_{kj}$ ,  $Z_i$  is  $\delta \omega_i^2$  by  $\omega_i^2$ . Where  $Z_i$  indicates the fractional change which is caused by the damage in the  $i$ th eigenvalue.

$\delta \omega_i^2$  is  $\omega_i^2$  minus  $\omega_i^{*2}$ , where  $\omega_i^2$  is the change in the frequency.

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$F_{ij}$  = fraction of Modal strain energy for  $i^{\text{th}}$  mode, which is stored in the  $j^{\text{th}}$  element of the structure.

$F_{ij}$  is given by the following expression:

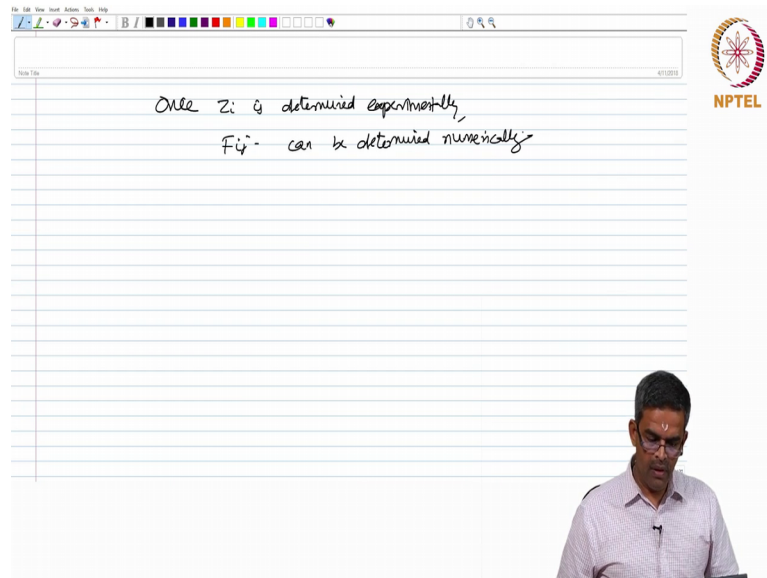
$$F_{ij} = \frac{[\phi_i]^T [K_j] \{\phi_i\}}{[\phi_i]^T [K] \{\phi_i\}} \quad (11)$$

Where  $\{\phi_i\}$  is the  $i^{\text{th}}$  mode shape vector  
 $[K]$  = system stiffness matrix  
 $K_j$  = contribution of  $j^{\text{th}}$  element to the system stiffness matrix

And  $F_{ij}$  is the fraction of modal strain energy for  $i$ th mode which is true in the  $j$ th element of the structure.  $F_{ij}$  is given by the following expression;  $F_{ij}$  is  $\phi_i$  transpose

$k_{ij}$  of  $\phi_i \phi_i^T k$  of  $\phi_i$ . Where  $\phi_i$  is the  $i$ th mode shape vector,  $k$  is the system stiffness matrix and  $k_{ij}$  is the contribution of  $j$ th element to the system stiffness matrix.

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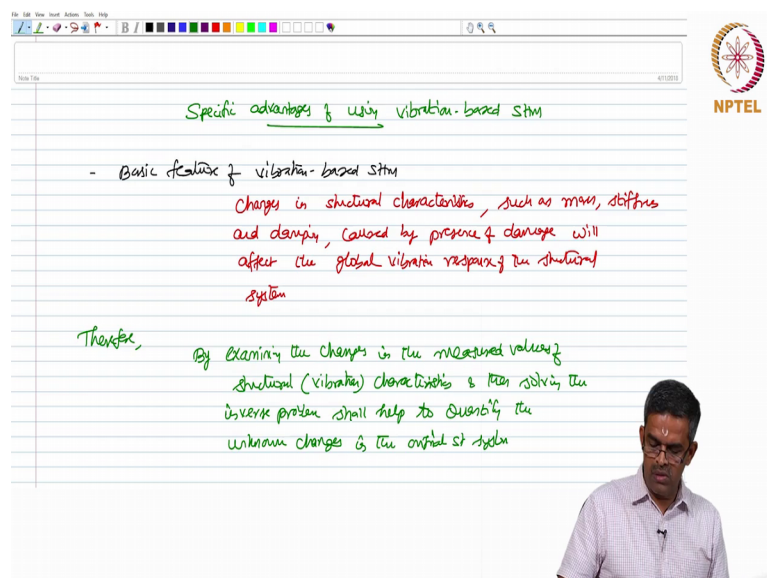


Once  $Z_i$  is determined experimentally,  
 $F_{ij}$  can be determined numerically.

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Once  $Z_i$  is determined experimentally,  $F_{ij}$  can be determined numerically. There are some special advantages of using vibration based SHM.

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Specific advantages of using vibration-based SHM

- Basic feature of vibration-based SHM  
Changes in structural characteristics, such as mass, stiffness and damping, caused by presence of damage will affect the global vibration response of the structural system.

Therefore, by examining the changes in the measured values of structural (vibration) characteristics & then solving the inverse problem shall help to quantify the unknown changes in the original system.

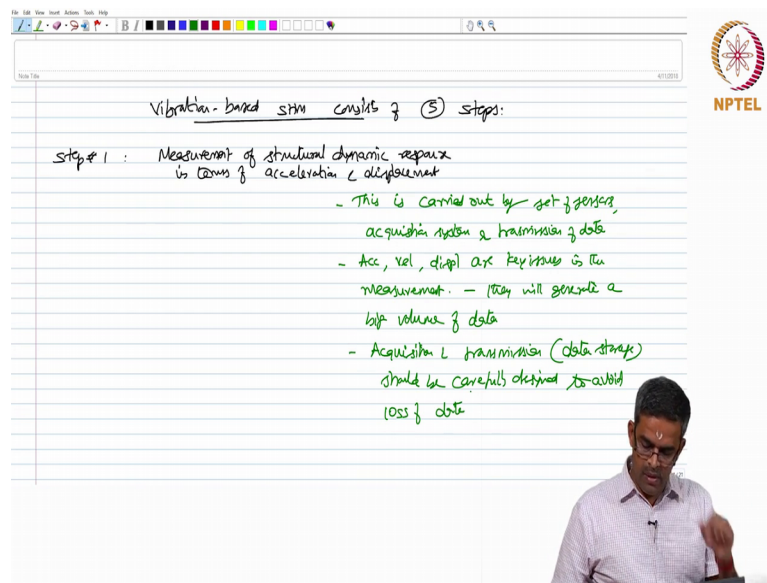
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Let us see what are the specific advantages of using vibration based SHM. To understand this let us try to get back slightly back forth and think about what is the basic feature of

vibration based SHM. The basic feature is changes in structural characteristics such as mass, stiffness and damping caused by presence of damage will affect the global vibration response of the structural system.

So, that is the basic feature. Therefore, by examining the changes in the measured values of structural characteristics that is vibration characteristics and then solving the inverse problem shall help to quantify the unknown changes in the original structural system.

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Vibration-based SHM consists of 5 steps:

Step # 1: Measurement of structural dynamic response in terms of acceleration & displacement

- This is carried out by set of sensors, acquisition system & transmission of data
- Acc, vel, displ are key issues in the measurement. - They will generate a big volume of data
- Acquisition & transmission (data storage) should be carefully designed to avoid loss of data

Vibration based SHM consists of therefore, 5 steps. Step number 1 deals with measurement of structural dynamic response in terms of acceleration and displacement. This is essentially done by set of sensors, acquisition system and transmission of data. Acceleration, velocity and displacement are key issues in the measurement. They will generate a big volume of data.

Therefore, acquisition and transmission which includes data storage also should be carefully designed to avoid any loss of data.

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The slide shows a presentation window with a toolbar at the top. The main content is handwritten text on a lined background. The text reads: 'Step #2: Characterization of initial structural model' followed by 'through both static & dynamic tests'. Below this, there are two bullet points: '- initial characterization provides the base line for comparing the response of the structure, before and after damage' and '- while the vibration characteristics of the functional structure are obtained by continuous monitoring, data acquired will be compared with the base line model'. In the bottom right corner, there is a small inset video of a man in a light-colored shirt and glasses, looking down. The NPTEL logo is visible in the top right corner of the slide area.

Step number 2, deals with characterization of initial structural model through both static and dynamic test. Initial characterization provides the baseline for comparing the response of the structure before and after damage, while the vibration characteristics of the functional structure are obtained by continuous monitoring.

Data acquired will be compared with the baseline model.

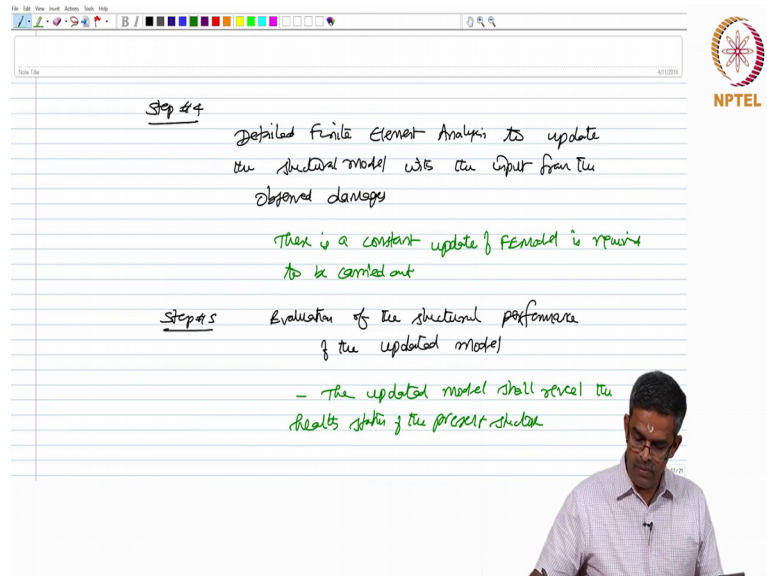
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The slide shows a presentation window with a toolbar at the top. The main content is handwritten text on a lined background. The text reads: 'Step #3' followed by 'continuous monitoring and damage localization of the structure'. Below this, there are two bullet points: '- data acquired/stored continuously should be analyzed for its comparison with the base line model' and '- Any significant change in the vibration characteristics can be leading to a damage localization'. In the bottom right corner, there is a small inset video of the same man from the previous slide, looking down. The NPTEL logo is visible in the top right corner of the slide area.

Step number 3, involves a continuous monitoring and damage localization of the structure. During this process, data acquired and stored continuously should be analyzed

for it is comparison with the baseline model. Any significant change in the vibration characteristics can be leading to a damage localization.

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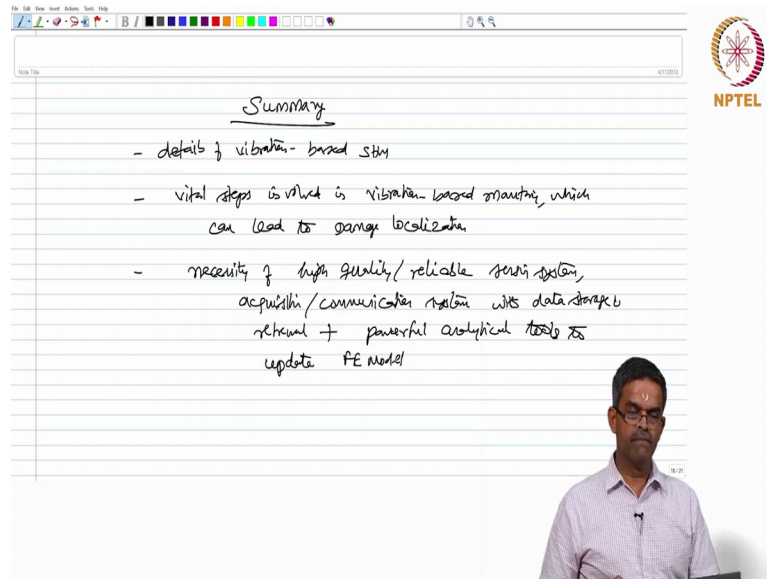
Step #4  
Detailed Finite Element Analysis to update the structural model with the input from the observed damages  
There is a constant update of FEM model is required to be carried out

Step #5  
Evaluation of the structural performance of the updated model  
- The updated model shall reveal the health status of the present structure

Step number 4, deals with Detailed Finite Element Analysis to update the structural model with the input from the observed damages. So, there is a constant update of the finite element model is required to be carried out. And in the last step is Evaluation of the structural performance of the updated model.

Now, at this stage, the updated model shall reveal the health status of the present structure.

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The image shows a digital whiteboard interface. At the top, there is a toolbar with various drawing tools and a color palette. The main area of the whiteboard contains handwritten text in black ink. The text is organized into a list under the heading 'Summary'. In the bottom right corner of the whiteboard, there is a small video feed of a man with glasses, wearing a light-colored shirt, who appears to be the presenter. The NPTEL logo is visible in the top right corner of the whiteboard area.

Summary

- details of vibration-based SHM
- vital steps involved in vibration-based monitoring, which can lead to damage localization
- necessity of high quality/reliable sensing system, acquisition/communication system with data storage & retrieval + powerful analytical tools to update FE model

So friends, in this lecture, we focused on to learn details of vibration based Structural Health Monitoring. We understood what are the vital steps involved in vibration based monitoring which can lead to damage localization. We have also seen what would be the necessity of high quality and reliable sensing system, acquisition and communication system with good data storage and retrieval plus powerful analytical tools to update the finite element models.

We will further continue discussions on methods of SHM monitoring in the coming lectures.

Thank you very much.