

Structural Health Monitoring (SHM)
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Lecture – 79

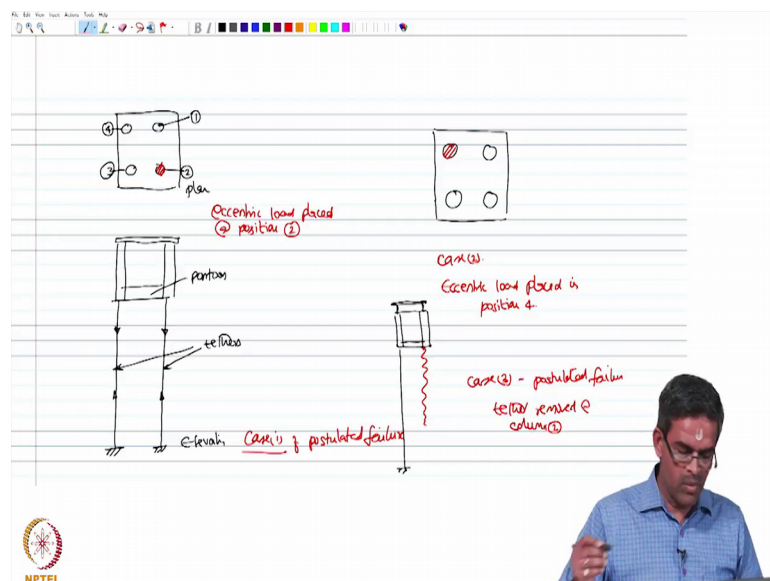
Part – 1: Structural Health Monitoring (SHM) of lab model of TLP - III

Friends, welcome to the 8th lecture in module 4. Now, we are going to continue the discussion what we had in the previous lecture. We are going to talk about the design of structural health monitoring system which has been done on the lab scale to investigate the damage analysis of a tension leg platform which is been subjected to postulated failure.

As such the TLP has not failed in the lab, an intended failure has been caused on the TLP model and we are now designing a structural health monitoring system. And an alert monitoring system to see whether the proposed SHM is capable of diagnosing the defect which has happened on the failed model and is it able to communicate the failure to the user client server as required through SMS and email etc. So, we are talking about structural health monitoring of a tension leg platform which is lecture 3 we are investigating it on the lab scale.

As I said one is interested to investigate the postulated failure, so let us say the postulated failure is an intended failure cost on the platform.

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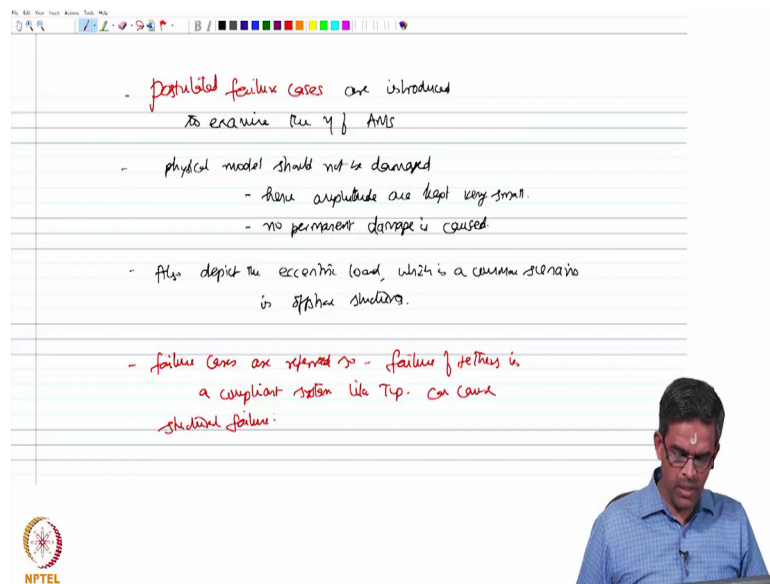


The platform is square in shape with 4 legs at each corner, let us say this is position 1, this is 2, and this is 3, and this is 4, this has got a deck on the top supported by columns and pontoon members at the bottom which are all anchored to the seabed using highly initial axial pretension tethers or let us say cables.

So, this is the pontoon as we have seen already in the last lecture, these are all tethers subjected to axial pretension and these are all the position of 1 2 3 and 4 this is of course, a plan and this is the elevation. In the postulated failure we create different cases let us say in case 1, in case 1 postulated failure there is an eccentric load kept on location 2. So, there is an eccentric load placed at position 2. Case 2 is an eccentric load placed in position 4. So, case 2 eccentric load placed in position 4.

We also have a case 3 if this is the elevation of the platform, these are the legs anchored to the seabed one of the legs is removed that is case 3 postulated failure where tether removed at column 2, ok.

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So, the postulated cases are introduced, I should say postulated failure cases are introduced to examine the efficiency of the alert monitoring system. However, the physical model should not be damaged ok, should not be damaged, hence the amplitude of waves are kept very small so that no permanent damage is caused, ok. So, the postulated failure cases also depict the eccentric loading which is a very, which is a common scenario in offshore structures.

Now, they are called failure cases because or referred so, because failure of tethers in a compliant system like TLP can cause failure really ok. I should say can cause your structural failure. So, now, we have seen there are 3 cases postulated case failure 1 with an eccentric load over column 2, you can see here column 2.

Postulated failure case 2 with eccentric load over column 4, then the case 3 is essentially the removal of legs at column 2 and case 4 is removal of leg at column 4 itself, that is removal of tether at position 4, ok. There are 4 cases we have examined the model is excited to a very high wave amplitude and then we want to see the damage condition, ok.

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mooring system

- taut-moored
- high initial pretension
- under axial tension

Sensors

- 4 sensors are deployed
- position of the sensor is changed for each set of the experiment

Assumption

In each postulated failure case, it is assumed that failure alone occurs in the platform.
(cumulative effect is ignored)

As far as mooring systems are concerned they are taut more with very high initial pretension they are only subjected to axial tension. As far as sensors are concerned 4 sensors are deployed, the position of the sensor is changed for each set of the experiment.

So, there is one assumption which has been made in this study which I will not highlight, in each postulated failure case it is assumed that failure alone occurs in the platform there is no cumulative effect of other failures on the platform. Cumulative effect is ignored only the failure occurs because of the postulated case that is an assumption made.

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The slide contains handwritten notes on a lined background. At the top, it is titled 'Sensor location' and lists two points: '- chosen, the max response is measured' and '- located @ the mass center of the deck.' Below this, it is titled 'Data processing' and lists two points: '- Signal-based data analysis' and '- processing of the significant variations of the acquired time history data'. A third point, '- alternatively, a frequency spectrum', is written in red ink. The NPTEL logo is visible in the bottom left corner, and a small inset image of a man in a blue shirt is in the bottom right corner.

Now, sensor locations are chosen such that the maximum response is measured. They are all located at the mass centre of the deck. So, now, the data processing during the experiments is done with the signal based data analysis, which involves processing of the significant variations of the acquired time history. One can also do alternatively a frequency spectrum.

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The slide contains handwritten notes on a lined background. It is titled 'signal-based data analysis' and states 'processing can be classified as'. Below this, it lists two categories: '(1) feature extract' and '(2) pattern recognition'. Under '(1) feature extract', it says 'feature extract process - process of time history data to extract sensitive damage features'. A third point, '- in the case of dealing with large data from multiple rooms', is written in red ink. Below this, it says 'This process condense the data into small set' and 'The processed is statistical'. The NPTEL logo is visible in the bottom left corner, and a small inset image of a man in a blue shirt is in the bottom right corner.

Now, in the moment you say signal based data analysis, then the processing can be classified as one feature extraction, two pattern recognition. The feature extraction

process involves processing of the time history data, to extract sensitive damaged features.

Now, in the case of dealing with large data, from multiple sensors this process condense in the data into small set which can be then you processed using statistical tools.

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The image shows a digital whiteboard with handwritten text. At the top, it says 'frequency domain technique'. Below that, there are three bullet points: '- to analyze the stationary event, which is localized in time domain', '- Fast Fourier Transform (FFT)', and '- power spectral density (PSD)'. To the right of these points, there is a vertical line and the text 'one word to analyze the data is frequency domain'. Below the bullet points, it says '- Short time Fourier transform (STFT)'. At the bottom, it says 'FFT is one of the best tools to identify the frequency components present in the signal'. In the bottom right corner, there is a small video inset of a man in a blue shirt and glasses. In the bottom left corner, there is an NPTEL logo.

The frequency domain technique to analyze the stationary event which is localized in timeline; So, the tools like fast Fourier transform FFT, power spectral density PSD, and short time Fourier transform which is STFT are used to analyze the data in frequency domain. We all do agree that FFT is one of the best tools to identify the frequency components present in the signal.

Little bit theory about the Fourier transform.


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Let $X(t)$ be time-varying function, which represents the acceleration time history that is measured (acquired) from the sensors during experiment.

Fourier transform $X(t)$ is given by

$$X(F) = \int_{-\infty}^{\infty} X(t) e^{-j2\pi Ft} dt \quad \text{--- (1)}$$

- FT decompose the signal into weighted combinations of sinusoids of different frequency
- Transform finds the amplitude & phase difference of these sinusoids



Let X of t be time varying function which represents the acceleration time history that is measured or you should say that is acquired from the census, during experiment.


Now, the Fourier transform X of t is given by X of F which is minus infinity to plus infinity, X of t e minus j 2 π of t d t . The Fourier transform decomposes the signal into weighted combinations of sinusoids of different frequency. The transform finds the amplitude and phase difference of these sinusoids.

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For a specific value f (F)

Signal is correlated with the basis function $e^{-j2\pi Ft}$

- value of f ranges from $-\infty$ to $+\infty$
- complex correlation coefft, obtained for this value f ($2\pi F$) is called Fourier Transform coefft.
- PSD of the signal represents distribution of power across different frequencies present in the signal.

$$S_x(F) = \lim_{T \rightarrow \infty} E \left\{ \frac{1}{2T} |X(F)|^2 \right\} = \lim_{T \rightarrow \infty} \frac{1}{2T} \left| \int_{-T}^T X(t) e^{-j2\pi Ft} dt \right|^2 \quad \text{--- (2)}$$


For a specific value of f the signal is correlated with the basic function $e^{-j2\pi ft}$. Now, the value of f ranges from minus infinity to plus infinity, complex correlation coefficient obtained for this value which is $X(f)$ is called the Fourier transform coefficient. The power spectral density function of the signal represents distribution of power across different frequencies present in the signal.

And is given by $S_X(f) = \lim_{T \rightarrow \infty} \frac{1}{T} |X_T(f)|^2$ where $X_T(f)$ is the expected value of $X(f)$ over the interval $-T$ to T .

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Eq (2) can be interpreted as
 expected value of FT of the signal, computed over an infinite period

- In FFT, only global features of the signal are extracted in the frequency axis
- There is no localization of the features across the time axis
- major deficit of FFT

- Transform is the result of summation of signal across the entire length

- a very frequency-resolution but a poor time-resolution



Equation 2, can be interpreted as expected value of the Fourier transform of the signal computed over an infinite period. There is an issue here, in Fourier transforms only global features of the signal are extracted in the frequency axis. Importantly there is no localization of the features across the time axis. This is seen as one of the major deficit of FFT.

Therefore, one can say transform is simply the result of summation of signal across the entire length of the signal; a very good frequency-resolution but a poor time-resolution.

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In case SHM, FFT can identify the damage
by presence of frequency spikes
but this damage thus identified is only
based on the information extracted from the freq value
- Information on time content is lost -

Alternatively, STFT
- This actually slices the signal into different segments
- using a window function



However, in case of structural health monitoring fast Fourier transform can identify the damage by presence of frequency spikes, but this damage thus identified is only based on the information extracted from the frequency value information on time content is lost.

So, what is the alternative? Alternatively one can use STFT, ok. What does it do? This actually slices the signal into different segments. How this is done? This is done using a window function omega of t.



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Each of these signals are subjected to FT
$$= X(\tau, \omega) = X(t) \omega(t-\tau) \quad (3)$$

where τ is the window function.
- window function is placed such that
Center of window coincides with start of the signal
and it traverses along the length of the signal.

$$X(\tau, \omega) = \int X(t) \omega(t-\tau) e^{-j\omega t} dt \quad (4)$$
$$X(\tau, \omega) = \int X(t) \omega(t-\tau) e^{-j\omega t} dt \quad (5)$$

τ is the center of window in time, ω is the mean frequency of the window



Now, each of these segments are subjected to Fourier transform which is equal to $X(\tau, \omega)$ will be $X(t) \omega(t - \tau)$, where t is the window function.

The window function is placed in such a manner, such that centre of the window coincides with start of the signal and it traverses along the length of the signal. Therefore, $X(\tau, \epsilon)$ is equal to $\int X(t) e^{-j\epsilon(t - \tau)} dt$ and $X(\tau, \epsilon)$ is also equal to $\int X(t) \omega(t - \tau) e^{-j\epsilon(t - \tau)} dt$, equation let us say 4, 5. In this case τ is the centre of the window in time, and ϵ is the main frequency of the window.