

Computer Methods of Analysis of Offshore Structures
Prof. Srinivasan Chandrasekaran
Department of Ocean Engineering
Indian Institute of Technology, Madras

Module – 02
Lecture – 08
Wave Spectra (Part - 1)

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- Random wave analysis
- Wave spectra
- Modified PM spectrum

So, friends, let us continue to discuss more on wave spectra, which are used as an input for environmental loads in offshore structures.

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The screenshot shows a handwritten slide from a presentation. The title is 'Module 2' and the subtitle is 'Lecture 8: wave spectra'. The main text reads: 'Wave loads - most important of all environmental loads act on offshore structures'. Below this, it says '- (2) separate solution - for determining these forces', with references in parentheses: '(Boaghe et al, 1998; Bas & Tim, 2007; Ertas and Lee, 1989)'. The slide is divided into two sections: 'First one - computation of sea state - idealized from the sea surface profile - $\eta(x,t)$, water-particle kinematics (appropriate wave theories)' and 'Second one - computation of wave forces on individual members and on total structure'. The NPTEL logo is visible in the bottom left corner.

We already said that wave loads are most important of all environmental loads **acting** on offshore structures. So, determining these wave forces has got two separate steps for determining these forces. This was verified interestingly by Boaghe Etal 1998 Bas and Tim 2007, Ertas and Lee 1989 what are these two steps? The first step is computation of sea state which is generally idealized from the sea surface profile; sea surface profile needs $\eta(x,t)$ and water particle kinematics which can be taken from appropriate wave theories. There are various number of wave theories available in the literature, I have discussed only Airy's wave theory.

I request the readers to read parallely other theories available from the reference literature given in the website of NPTEL of this specific course, the second one is computation of wave forces on individual members and on total structure. So, there are two structures involved in this.

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The screenshot shows a handwritten slide in a presentation software. The title is "different analyses". The content is as follows:

- ② different analyses
- 1) single design wave analysis
- 2) Random wave analysis
- a) Single design wave analysis
 - A regular wave is considered
 - design wave
 - (H_d, T_d) are known (Given as Input)
 - Return period - 100 years
 - Forces induced by the design wave - higher order wave theory
 - Stokes' fifth order wave theory

One can look into two different analyses, one could be single design wave analysis other could be random wave analysis. In single design wave analysis a regular wave is considered, this wave is termed as a design wave whose wave height and wave period are known. In fact, they are given as input return period of this wave, the design wave is generally chosen to be 100 years. We already know return period we already understood this concept. So, forces induced by the design wave are computed using higher order wave theory, just for our understanding one of the higher order wave theories is stokes fifth order wave theory.

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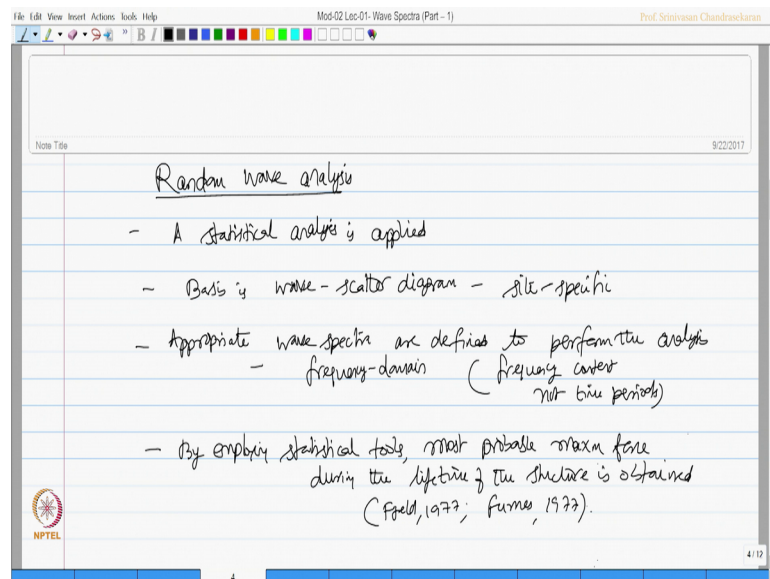
The screenshot shows a handwritten slide with the following content:

- Dynamic response behavior of the structures - Not addressed (Bea et al, 1999; Ertas & Lee, 1999)
- static analysis is appropriate - single design wave analysis
 - Dominant wave - single design wave
 - period above all other waves
 - well apart from period of the platform.
- This is applicable in case of Extreme waves (Storm waves) or shallow water structures (Bas & Tani, 2007; Bovingius et al 2005 etc)

It is very important to note dynamic response behavior of the structure is not addressed in this design methodology, references can be seen at Bea et al 1999, Ertas and Lee 1989. Usually static analysis is considered to be appropriate for design wave approach, for single design wave analysis.

This is due to the simple reason that the dominant wave which is considered as a single design wave has wave periods above all other waves in the ensemble and this period is well apart from period of the structure. Generally this is applicable this method is applicable in case of extreme waves, which can be a storm wave on shallow water structures this can be verified by papers published Bas and Tim, Boyunguo et al etcetera.

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The other approach is random wave analysis, in this approach a statistical analysis is applied the basis is wave scatter diagram this is of course, site specific. So, one has to choose an appropriate wave scatter diagram for a specific offshore installed site and do statistical analysis on that.

So, an appropriate wave spectra are defined to perform the analysis, the analysis is usually carried out in frequency domain. So, the frequency content will be focused not the time content. Once you do this by choosing an appropriate wave spectra, then by employing statistical tools, one can get the most probable maximum force during the life time of the structure. This can be verified by Fjeld 1977 and Furnes 1977. So, it is important to choose appropriate wave spectra.

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- Appropriate wave spectra is to be chosen
- wave theories
 - Airy's linear wave theory
 - Stokes 5th order wave theory
 - Solitary wave theory
 - Cnoidal wave theory
 - Dean's stream function theory
- Airy's theory - useful for preliminary force estimates
 - Does not address the submerged length - changes continuously with passage of waves - MSL itself
 - Variable submergence effect - stretching modification

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So, different wave theories will give different water particle kinematics just to name them common theories are Airy's linear wave theory, Stokes fifth order wave theory, Solitary wave theory, Cnoidal wave theory, Dean's stream function theory.

So, in general Airy's theory is useful for preliminary force estimates as we all know Airy's wave theory does not address the submerged length which changes continuously with passage of waves whereas, Airy's theory stops at MSL itself. So, this variable submergence effect is generally addressed by stretching modifications which we briefed in the last lecture.

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Even with stretching modifications, linear theory is not adequate to describe water particle kinematics completely.

- many non-linear wave theories are employed in the analysis

classification	d/L	kd	$\tanh(kd)$
deep water condition	$1/2$ to ∞	π to ∞	≈ 1
Transitional water condition	$1/20$ to $1/2$	$\pi/10$ to π	$\tanh(kd)$
shallow water	$(0$ to $1/20)$	$(0$ to $\pi/10)$	$\approx(kd)$

But; however, literature show even with stretching modification, linear theory is not adequate to describe the water particle kinematics completely.

Therefore many non-linear wave theories are employed in the analysis, now the theory is also related to different classifications depending upon the water depth, there are various ratios d by L , $k d$ and let us say \tan hyperbolic $k d$. If this value is between half to infinity and if this is between π to infinity and this is approximately one we call this as a deep water condition if this is between 1 by 20 to half and this is π by 10 to π and this is simply \tan hyperbolic $k d$ itself then we call this as transitional water depth, if this anywhere from 0 to 1 by 20 and 0 to π by 10 and this is minus approximately $k d$ itself we call this as shallow water, as per the definition in the literature. Once we agree that linear theory cannot express the forces satisfactorily then wave spectra are being employed for calculating forces in offshore structures.

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The image shows a digital whiteboard with handwritten notes in red ink. At the top, the text "wave spectra" is underlined. Below it, the text "(1) Modified p-M spectrum" is written. The main equation is $S^t(\omega) = \frac{5}{16} H_s \left(\frac{\omega_0^4}{\omega^5} \right) \exp \left\{ -1.25 \left(\frac{\omega}{\omega_0} \right)^{-4} \right\}$. Below the equation, the parameter ω_0 is defined as $\omega_0 = \sqrt{\frac{2g}{3U_w}}$, where U_w is the mean wind speed. Finally, H_s is defined as "Significant wave Ht (m)".

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wave spectra

(1) Modified p-M spectrum

$$S^t(\omega) = \frac{5}{16} H_s \left(\frac{\omega_0^4}{\omega^5} \right) \exp \left\{ -1.25 \left(\frac{\omega}{\omega_0} \right)^{-4} \right\}$$

where $\omega_0 = \sqrt{\frac{2g}{3U_w}}$ $U_w = \text{mean wind speed}$

$H_s = \text{Significant wave Ht (m)}$

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The first one is a very common form being used this is called modified Pierson Moskowitz spectrum, this says the spectral density is 5 by 16 H s omega 0 to the power 4 by omega 5 exponential minus 1.25 omega by omega 0 to the power minus 4 where omega 0 is given by 2 g by 3 u w, where u w is the mean wind speed for the specific site h s is significant wave height in meters.