

Classification of offshore structures

A classification in degree of non-linearities and importance of dynamics.

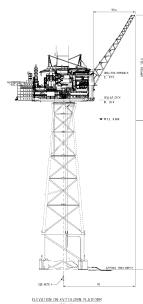
Sverre Haver, StatoilHydro, January 2008

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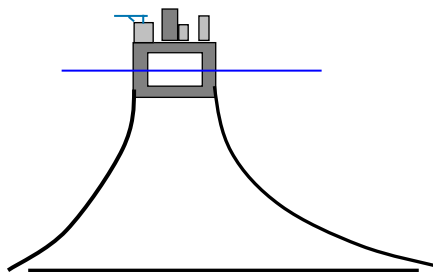
A first classification of structures

Fixed



Rather small motions
in particular vertical.

Floating



Large motions vertically,
very large motions horizontally
depending on mooring system.

Articulated



Very large motions horizontally,
small motions in vertical plane

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Load generating environmental processes

- Waves.

Wave severity changes in two time scales; 1) Slowly varying (period in the order of hours) average characteristics (significant wave height and characteristic wave period), 2) Rapidly fluctuating individual waves. Instantaneous load caused by the rapid process.

Typical period range in storms regarding the rapid fluctuations: 5 – 25s.

- Wind

Wind severity is also varying in two time scales: 1) Slowly varying mean characteristics, 2) Relatively rapid fluctuating instantaneous wind speed.

Instantaneous process is caused by the instantaneous wind!

Typical period range for fluctuating wind is: 1s – minutes

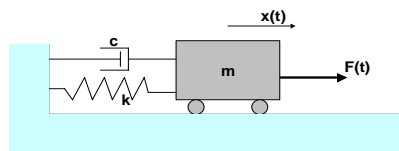
- Current

Current speed will vary slowly with time. For practical applications current is most frequently considered as constant flow speed.

Typical period for fluctuations: Very long (order hours)

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How to calculate motions of structures? Idealized example: Single degree of motion



Assuming linear mechanical system and linear external load:

$$m\ddot{x} + c\dot{x} - kx = F(t)$$

Assuming a sinusoidal wave process of frequency ω , $F(t)$ will also be sinusoidal with some amplitude f_0 and frequency ω . The solution will also be exponential, $x(t) = x_0 \sin(\omega t + \theta)$ with:

$$x_0(\omega) = \frac{f_0}{k} \left[\frac{1}{1 - \left(\frac{\omega}{\omega_0}\right)^2 + 4\lambda^2 \left(\frac{\omega}{\omega_0}\right)^2} \right]^{\frac{1}{2}}$$

and

$$\theta(\omega) = \arctan \left[\frac{2\lambda \frac{\omega}{\omega_0}}{1 - \left(\frac{\omega}{\omega_0}\right)^2} \right]$$

with:

$$\omega_0 = \sqrt{\frac{k}{m}}$$

, natural frequency

$$\lambda = \frac{c}{c_{critical}}$$

, damping ratio

Observations:

$\omega \rightarrow 0$: $X_0 = f_0/k = x_{static}$
 $\theta = 0$ (in phase)

$\omega \rightarrow \omega_0$: $X_0 \rightarrow \text{infinity}$
 $\theta = 90^\circ$ out of phase

$\omega \rightarrow \gg \omega_0$: $X_0 \rightarrow 0$
 $\theta = 180^\circ$ out of phase

Dangerous situation

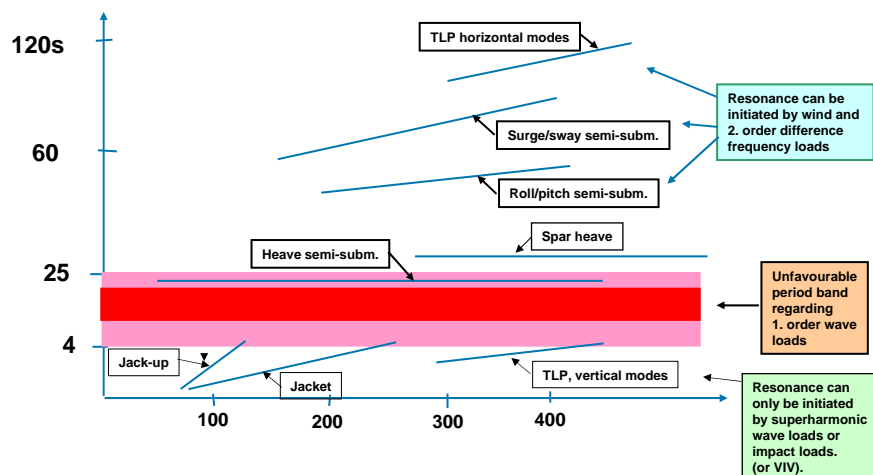
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Which natural periods ($=2\pi/\omega_0$) do we phase for offshore structures?

- Fixed platforms:
 Jackets and GBS's: About: 1s for depth < 100m, 3-5s for 200-250m depth
 Jack-ups: About: 4-5s for depth of about 90 150m (depending on foundation solution).
- Floating platforms:
 Heave semi-submersible: 23 – 26s
 Surge/sway of catenary moored semi submersible: 60 – 90s
 Pitch/Roll of semi submersible: 30 – 50s
 Heave of Cell spar platform (see next page): 25 – 35s
 Surge/sway of taut moored spar: 2 – 3 min.
 Roll – pitch of spar: about 1 min
- Articulated platforms
 Heave TLP 2 – 3s
 Surge/sway of TLP (300 – 400m depth): 1 – 2 min.
 Roll/Pitch of TLP: 2 – 3.5s

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Largest natural period versus depth for some platform concepts (illustrative figure).



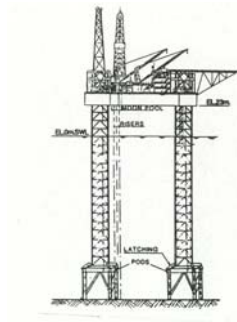
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Example of fixed platforms

Gravity Based Structure



Jacket



Jack-up



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Classification of response problems

Equation of motion – general form – for a single degree of freedom problem:

$$m\ddot{x}(t) + c(x, \dot{x})\dot{x}(t) + k(x, \dot{x})x(t) = F(t)$$

We will introduce the following definitions regarding nature of the response problem:

Linear mechanical system if: $c(x, \dot{x}) = c$ **and** $k(x, \dot{x}) = k$

Non-linear mechanical system otherwise.

If the right hand side of eq. of motion, $F(t)$, is a linear function of the surface process assumed to be Gaussian, we will refer to the response problem as a linear response problem.

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Linear response problem

Facts:

- * Sea state is characterized by the wave spectrum, $s_{\xi\xi}(f)$.
- * The response properties are defined by the transfer function, $h_{\xi x}(f)$
- * The response process will also be a Gaussian process.

(Transfer function for frequency, f , is the complex response amplitude of when the system is exposed to a harmonic wave of unit amplitude. The absolute value of the transfer function is real response amplitude, i.e. phase information is lost. This quantity (the absolute value of the transfer function is called response amplitude operator, RAO(f)).

The response process is completely characterized by the response spectrum which is given by:

$$s_{xx}(f) = |h_{\xi x}(f)|^2 s_{\xi\xi}(f)$$

When we are utilizing this approach we say that we solve the problem in the frequency domain! The only parameter involved in the Gaussian distribution (for a process of zero mean) is the variance which is given as the area under the response spectrum.

Summary: For a linear response problem, we prefer to do the analysis in the frequency domain. This approach can be utilized both for a short term analysis and a full long term analysis.

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Non-linear loading – example drag type loading I

The non-linear drag load will often be governing in extreme wave conditions for jackets and jack-ups.

$$f(z,t) = \frac{1}{2} \rho c_D d u(z,t) |u(z,t)| + \frac{\pi}{4} \rho c_M d^2 \ddot{u}(z,t)$$

Drag term,
 $u(z,t)$ is particle speed.

Mass – or inertial term,
proportional to
acceleration

If T_0 is shorter than the energetic wave periods, we can neglect the inertia term and the damping term of the equation of motion. Solution becomes:

$$x(t) = \frac{F(t)}{k}$$

Summary: If dynamics can be neglected, we primarily have to find the instantaneous maximum of the total load acting on the structure. This is most frequently done by utilizing the Design Wave Method using a Stoke 5th order wave profile. A critical task is to predict proper height and period of the design wave. (We will come back to this.)

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Non-linear loading – example drag type loading II

If the structural period is approaching the energetic wave period band, dynamics can not be neglected.

For cases where the drag term represent a modest part of the total load, we may linearize the load function. → We have a linear response problem and can use the methods suggested for such a system. (This can often be done for fatigue assessments.)

If the drag term is important (maybe even governing), the situation is:

Response process is no longer Gaussian and maxima not Rayleigh distributed
The transferfunction is no longer a proper system characteristic.
The sea surface is still characterized by the wave spectrum

What can we do in order to find the short term distribution of response?

Solving the equation of motion in the time domain. We will come back to this!

A time domain solution is typically very fast as far as the mechanical system is non linear, i.e. no updating of damping and stiffness is necessary.

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Non-linear loading – example drag type loading III

A warning regarding dynamics of drag-dominated structures

Background: An effect of non-linearity in the load function is that even if the structure is exposed to a harmonic wave with frequency ω , the load function will show some energy at multiples of the frequency. This can be a problem if these higher frequencies hit a lightly damped structural mode.

The total drag load on a vertical pile in deep water exposed to a sinusoidal wave is given by:

$$L(t) = \frac{1}{2} \rho c_D d \omega^2 \xi_0^2 \int_{-\infty}^{\xi_0 \sin(\omega t)} \kappa_0^2(z) dz |\sin(\omega t)| \sin(\omega t), \text{ where for our purpose we use: } \begin{matrix} \kappa_0^2(z) = e^{-2kz} & z \leq 0 \\ \kappa_0^2(z) = 1 & z > 0 \end{matrix}$$

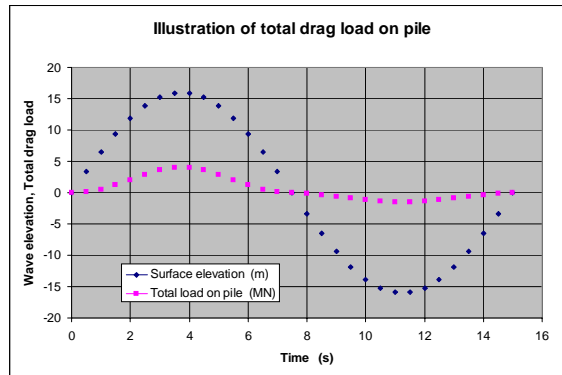
Numerical values used are: $\rho = 1025 \text{ kg/m}^3$, $c_D = 1$, $d = 4 \text{ m}$, $\omega = 0.419 \text{ rad/s}$ and $\xi = 16 \text{ m}$

The surface elevation and the corresponding load are shown in next slide:

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Non-linear loading – example drag type loading IV

A warning regarding dynamics of drag-dominated structures cont.



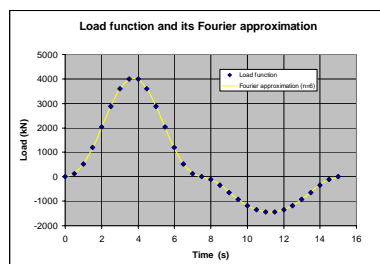
→ It is seen that the load history is not of a sinusoidal shape!

A Fourier approximation is shown next slide:

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Non-linear loading – example drag type loading V

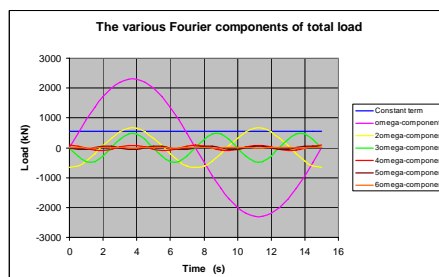
A warning regarding dynamics of drag-dominated structures cont.



Summary: If 2ω and 3ω terms hit a lightly damped natural mode, large response can be experienced.

Note the constant term. For a process with varying wave crest heights this is one source for a slowly varying force that can hit natural periods of floaters.

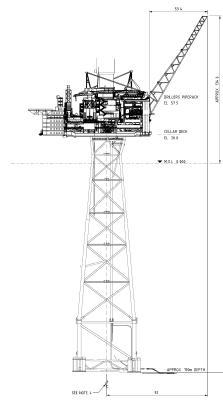
The various Fourier components up to 6 are shown below. It is observed that both the 2ω and the 3ω term are of a considerable amplitude.



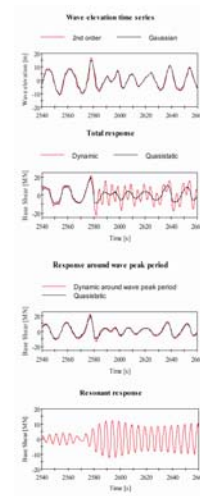
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Example of 3ω - excitation

Response of Kvitebjørn jacket



Kvitebjørn



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Non-linear mechanical system

Such a system will often be time consuming if one is solving the equation of motion in the time domain. c and k may depend on the response and will therefore have to be updated by some iteration process between two time steps.

An alternative approach for such systems is model testing.

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