Several softwares are used in the analyses in this master thesis. In the project thesis, Wasim was the main software, and it has also been used in this thesis. In addition Wasim Harmonic and Waqum explorer have been used. Here follows a short description of these softwares. The Wasim introduction is similar to the one given in the project thesis.

0.1 Wasim

Wasim is a hydrodynamic program developed by DNV. Wasim can run non linear hydrodynamic analysis in time domain on both fixed and floating vessels. This includes the calculation of global motions and local pressure loads. Wasim is part of the HydroD package, and was originally designed for ships with forward speed.

Wasim solves the fully 3-dimensional diffraction/radiation problem by use of the Rankine panel method. The problem is solved on the mean surface and mean wetted surface. This requires panels on both the structure model and the free surface[**?**]. The Rankine panel model is an effective and robust method to predict wave induced response of general three dimensional floating structures. The method is able to handle various free-surface conditions. This means it can take into account the coupling between steady and unsteady flow fields around a floating vessel. To take care of the radiation conditions waves are absorbed by a numerical beach. The theoretic basis of Wasim is based on a method developed by Kring et al. [**?**].

The following explanation of the modelling of the velocity potential and damping is from an article by Zhi Shu and Torgeir Moan [**?**].

$$\Phi = \Phi_B + \Phi_I + \Phi_m + \Phi_l \tag{1}$$

Here

- Φ_B is the base flow, it accounts for the presence of the hull even though it does not satisfy the actual boundary conditions for the ship, but only depends on the submerged hull.
- Φ_I is the incident wave potential, it represents the incoming flow. In most cases a set of sinusoidal waves.
- Φ_m is the memory flow, it represents the reflection of the waves on the hull. Purpose is to cancel the effect of the incoming wave at the hull, and make sure the free surface conditions are satisfied.
- Φ_l is the local flow. The local flow basically represents the response of the ship. On the free surface local flow is zero , which means that the local flow is only dependent on the motion of the body, not on the wave frequency.

These velocity potentials have to satisfy the following flowing conditions in the fluid domain:

$$\nabla^2\Phi = 0 \quad \text{in fluid domain} \quad (2)$$

$$\Phi_l = 0 \quad \text{on } z = 0 \quad (3)$$

$$\frac{\partial\zeta}{\partial t} - (U - \nabla\Phi_B)\nabla\zeta = \frac{\partial^2\Phi_B}{\partial z^2}\zeta + \frac{\partial\Phi_l}{\partial z} + \frac{\partial\Phi_m}{\partial z} \quad \text{on } z = 0 \quad (4)$$

$$\frac{\partial\Phi_l}{\partial t} - (U - \nabla\Phi_B)\nabla\Phi_l = -g\zeta + U\nabla\Phi_B - \frac{1}{2}\nabla\Phi_B\nabla\Phi_B \quad \text{on } z = 0 \quad (5)$$

$$\frac{\partial\Phi_I}{\partial n} = \nu_n \quad \text{on the body surface} \quad (6)$$

$$\frac{\partial\Phi_m}{\partial n} = -\frac{\partial\Phi_I}{\partial n} \quad \text{on the body surface} \quad (7)$$

Hydrodynamic pressure on the body is defined by Bernoulli's equation:

$$p - p_a = \rho(gz + \frac{\partial\Phi}{\partial t} + \frac{1}{2}\nabla\Phi\nabla\Phi) \quad (8)$$

Wasim accounts for some, but not all non linear effects. The non-linear effects included are:

1. Varying wetness
2. Non-linear hydrostatics
3. Non-linear Froude-Kriloff forces
4. Inertia and gravity terms

These non-linearities can contribute considerably to motions and global loads in large waves. However the radiation forces and diffraction wave force is still given by linear theory [**?**]

In Wasim, the roll damping is modelled quadratically:

$$B_{44} = B_1 + B_2|\dot{\eta}_4| = (b_1 + b_2\frac{|\dot{\eta}_4|}{\omega_4})B_4^{crit} \quad (9)$$

- B_{44} is the roll damping coefficient
- B_1 is the linear damping coefficient
- B_2 is the quadratic damping coefficient
- ω_4 is the eigenfrequency in roll

- b_1 and b_2 is user defined. b_1 is defined as a fraction of the critical damping. b_2 is given i the unit 1/degrees, defined such that multiplied with $\frac{|\dot{\eta}_4}{\omega_4}$ it becomes a fraction of the critical damping.

Wasim models waves as Airy waves. This means that the program does not model non-linear irregular sea. When input for an irregular sea state is given, HydroD transforms it to a regular wave set.

0.2 Wasim Harmonic

Wasim Harmonic is basically Wasim split in two. THe radiation and diffraction problems are calculated separately. This makes the program more robust.

0.3 Notes from Ogilvie

Cummins one major assumption: Linearity of system, extends to cover excitations of any nature. If ship given impulse it will have response lasting much longer than the duration of the impulse. Succession of impulses, response at any time assumed to be a sum of responses to individual impulses. Impulses can be assumed to occur closer and closer together until they are integrated instead of added. Very useful approach. Find that the existence of the free surface causes the physical system to have a ¨memory. What happens at one time instance affects the system for all time after.

Impulse response method exhibits very clearly the basic contribution of the free surface to the problem.

0.3.1 Relations betwen TD and FD

How a ship in a confused sea would be able to respond to each frequency component as if the wave of that frequency existed separately.

0.4 Waqum Explorer

Waqum is an impulse response function based simulator performing hydrodynamic analysis in the time domain. It uses retardation functions to describe motion of floating bodies and can handle non-linear loads.

A linear analysis is performed in the frequency domain and the hydrodynamic coefficients from this analysis is the input in Waqum. Through impulse response functions this input is then translated into the time domain.

The motion of a floating structure, $x(t)$, can be described by the equation of motion. The equation is based on the assumption that no parts of the equations depend on the absolute time except from the excitation force and response.

$$[M + A(\omega)]\ddot{x} + B(\omega)\dot{x} + Cx = Fx \tag{10}$$

Here the different coefficients are as follows:

- M, structural mass and inertia
- A, added mass, dependent on frequency
- B, damping, dependent on frequency
- C, restoring force
- F, Excitation force proportional to x (harmonic)

The response, $x(t)$, to an arbitrary force, $f(t)$, in a linear system can by use of the response $r(t)$ to a unit impulse be written as follows:

$$\int_{-\infty}^{+\infty} f(\tau) r(t-\tau)\, \mathrm{d}\tau \overset{casuality}{=} \int_{-\infty}^{t} f(\tau) r(t-\tau)\, \mathrm{d}\tau = f \otimes r \tag{11}$$

Because one can assume that no response can come from an impulse before it happened, the convolution integral can be limited to an upper limit t. Here $\otimes$ is the convolution operator.

0.5 The retardation function

Orgilvie gives the following expressions for the retardation function:

$$h(t) = \frac{2}{\pi} \int_0^\infty b(\omega) \cos(\omega t)\, \mathrm{d}\omega \tag{12}$$

$$h(t) = -\frac{2}{\pi} \int_0^\infty \omega a(\omega) \sin(\omega t)\, \mathrm{d}\omega \tag{13}$$

An analytical model must be crated and one way of validating the model is to find the retardation function and use it in the following equations found from Orgilvie. This operation is quite easy to perform numerically.

$$A(\omega) = A^\infty - \frac{1}{\omega} \int_0^\infty h(t) \sin(\omega t)\, \mathrm{d}t \tag{14}$$

$$B(\omega) = B^\infty + \int_0^\infty h(t) \cos(\omega t)\, \mathrm{d}t \tag{15}$$

0.6 From hydroelasticity LN:

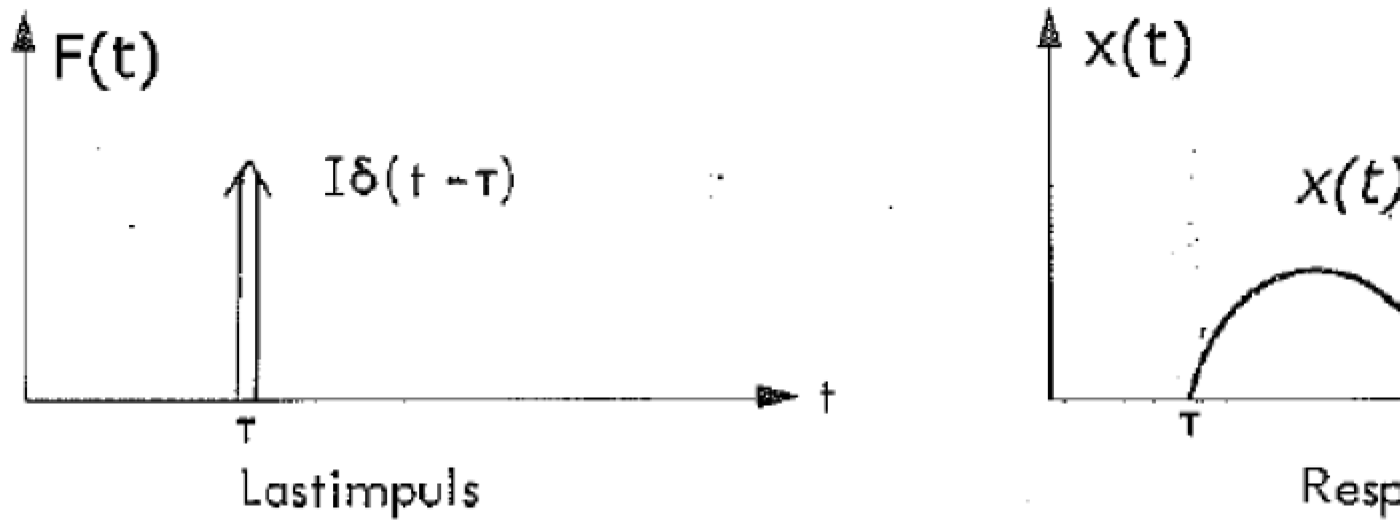
Non-harmonic loading - Transient Response

When a dynamic system is excited by a non periodic load, $F(t)$ the result will be a transient response. For the general time dependent force the problem can be solved by numerical integration. Fourier theory may also be used by representing the general non-periodic excitation as a sum of harmonic components or by the impulse-response method. It is the impulse response function which will be discussed here.

In the impulse response method it is assumed that an arbitrary excitation, $F(t)$ can be represented by a superposition of very short impulse excitations. The solutions for each of the impulses are super positioned to give the total response of a linear dynamic system.

Impulse is the time integration of the force

$$I = \int F(t)\,\mathrm{d}t \tag{16}$$



Fundamental assumptions in the convolution method approach are:

- We assume that the structural dynamic system is linear. This imply that there is a linear relationship between force and response
- A nonlinear force model is allowed. The relationship between incident wave and force may be nonlinear

0.6.1 Frequency dependence of added mass and damping

Both the added mass and the hydrodynamic dampin are (in general) dependent on the frequency of oscillation. This means that the values changes with frequency and mode of oscillation. When load case is time dependent, the frequency dependency of the added mass and damping introduces a memory effect on the system. This effect should be included in the response calculation and one way of doing it is through the retardation function.

For high frequencies the added mass and damping coefficients reach asymptotic values. One may therefore split these coefficients as follows:

$$A(\omega_e) = A^{\infty} + a^0(\omega_e) \tag{17}$$
$$B(\omega_e) = B^{\infty} + b^0(\omega_e) \tag{18}$$

Here ∞ indicated the high frequency asymptote, while 0 is the deviation from this value. If this is used in the equation of motion, the equation of motion will look something like this:

Here ( ) , g t k i is the retardation function for the different mode of motions. The retardation function is determined from frequency dependent added mass and damping as follow;

The new equation of motion can now be used for an arbitrary time dependent loading and is solved in time domain by numerical integration. However the numerical implementation of the integral term for the retardation function to include the frequency dependency of added mass and damping is not straight forward.

0.6.2 Damping

As shown in the paragraph above, the retardation function can be calculated from either the added mass or the damping. If the function is found through the damping, a continuous representation of the damping, $b(\omega)$ is required. The asymptotic behaviour of two quantities connected by the Kramers-Kroning relationship is such that the added mass and damping coefficients can be approxiamted by short inverse power series. In Waqum the continous representation of the damping is as follows:

$$B(\omega) = \begin{cases} \hat{B}(\omega) & \text{for } \omega \leq \omega_u \\ B^{\infty} + \frac{k_1}{\omega^2} & \text{for } \omega > \omega_u \end{cases} \tag{19}$$