Diffraction of Steep Waves for stationary Vessels

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Introduction

The calculation of the wave drift forces in irregular waves has matured over the last 15 years. The theory of pressure integration or impulse balance considerations are much used concepts in frequency domain type of boundary element programs. However for non-linear situations, such as wet–dry variations of the hull of the vessel or the steepness of the incoming waves no direct numerical tools are available. The best available approaches are based on rankine type of sources distributed over a unknown boundary such as the wetted part of the vessel and the free surface around the vessel. These rankine type of approaches still require a vast amount of computational efforts. e.g. see Huijsmans [4]. Approximative theories that have been developed over the last 5 to 10 years are mostly based on a linearized description of the free surface, taking into account the actual wetted surface by integrating the undisturbed incoming wave pressures up to the linearized free surface level. This kind of approach has succesfully been applied for the assesment of capsizing capabilities of frigates in stern quartering irregular seas, using basically strip theory type of approximations for the fluid reaction forces. In this study we will identify the non-linearity effects in the waves on the wave drift forces using techniques that have been developed to estimate effects of passing ships on its environment see Pinkster [2] and Bingham ([1], [3]) In the next section we will explain how a part of the wave non-linear effects can still be handeled using linear potential flow boundary element programs, such as DIFFRAC or WAMIT.

Approximation requirements

The approximation that will be presented hinges around a splitting of the fluid potential flow into two parts, ie:

$$\phi = \phi_w + \phi_m$$

Here ϕ_w is the potential of the wave diffraction effects and ϕ_m is the potential of the motion reaction effects. In the following we will assume that the potential ϕ_m will obey the well known linearized boundary conditions at the free surface, body surface ,the sea floor condition and the radiation condition. For the potential ϕ_w we will assume that waves can be split into an incoming wave and a diffracted wave. So far this is also the case for the linearized diffraction theory ; however we will now assume that the incoming wave is described as a non-linear wave and satisfies the non-linear dynamic and kinematic free surface conditions. This non-linear wave can be computed off-line eg with a non-linear FEM code. This can even be a 2-D version, since we for the time being assume that the incoming wave is longcrested. A good overview of this type of non-linear theories can be found in the work of Westhuis [5]. Applications of this work to the excitation on heeled shipsections can be found in [4]. Based on the knowledge of the evolution of the free surface and the velocity profiles below the free surface, the body boundary conditions can be generated on the vessel. In essence they are non-linear. We will assume however, that the body boundary conditions will only be applied up to the mean waterline. At each point of the mean wetted hull of the vessel a time trace can be generated of the normal velocity components. Once the time trace of the normal velocity at the hull is known we are able to generate all the spectral components (and phase angles) of the normal water velocities. Therefore we can generate the correct spectral components of the normal velocity over the hull with the correct phase characteristics. These normal velocity components are then used as input to a standard wave diffraction programs. As a result, we can generate, using FFT techniques, the correct spectral distribution of the diffracted wave pressures also including the correct phase angles or spatial distribution. Assuming the undisturbed incoming wave profile as known, we can calculate the total wave force on the mean wetted hull of the vessel. We note that the water pressures in the area above the free surface can only be considered using the undisturbed wave pressures up to the wave profile. Once the pressures over the whole relevant spectral domain are known we can calculate the time serie of the wave pressures using an inverse FFT. Integration over the whole wetted surface of the vessel will produce the correct first order and second order wave forces.

Approximation

In short a review of the procedure for determining the wave drift forces in steep waves:
Determine the normal velocities on the mean wetted surface of the vessel:

$$\underline{v} \cdot \underline{n}\,(t) = V_x^{wave}\,(t)\,n_1 + V_y^{wave}\,(t)\,n_2 + V_z^{wave}\,(t)\,n_3$$

The coefficients n_1, n_2, n_3 are the x,y and z components of the normal vector $\underline{n}$.
Here the V_x^{wave} resp y and z water velocities will come from a non-linear approximation of the steep water wave,eg using a second order approximative method or an non-linear free surface flow solver like HUBRIS, see [5]. Even a finite sinusoidal type of wave will lead to non-linearities in the wet–dry zone near the free surface.
After an FFT of the normal velocities we will find:

$$\underline{V}\,(\omega) \cdot \underline{n} = \mathcal{F}\left(\underline{v} \cdot \underline{n}(t)\right)$$

In which $\mathcal{F}$ signifies the FFT on the normal water velocities at the mean wetted hull. Using linearized potential flow programmes like DIFFRAC or WAMIT we are then able to generate all the in phase and out of phase pressures in frequency domain for all the panels upto the mean waterline. Hence an inverse FFT on the water pressures will produce a time trace of the diffracted wave pressures:

$$P_{diffracted}\,(t) = \mathcal{F}^{-1}\left[P_{diffracted}\,(\omega)\right]$$

In which $\mathcal{F}^{-1}$ signifies the inverse FFT. Once the diffracted wave pressures are known we can determine the total wave pressures:

$$P_{total}\,(t) = P_{diffracted}\,(t) + P_{incoming}\,(t)$$

The same applies for the diffracted water velocities and the pressure gradients. Using the standard wave force calculations using pressure integration, we can generate time series of the first order and second order wave forces. The above outlined procedure has been applied to a container vessel. In figure(1) the dimensionless diffraction part of the pitch exciting moment is displayed as a function of time. Here the input was a regular wave of wave amplitudes varying from 0.001 m to 5.0 m. The 0.001m amplitude corresponded very well with the results from linear diffraction code. The number of frequency components used for this example amounts to 8. The undisturbed wave pressures can be integrated upto the undisturbed intersection of the wave and the vessel. One distinct disadvantage attaches to this way of computing the wave drift forces in steep waves,ie for each different wave condition a complete new set of diffraction calculations have to be made. The amount of CPU effort depends on the non-linear complexity of the wave field,hence the highest frequency present in the incoming water velocity profile. This has to be investigated more in detail.

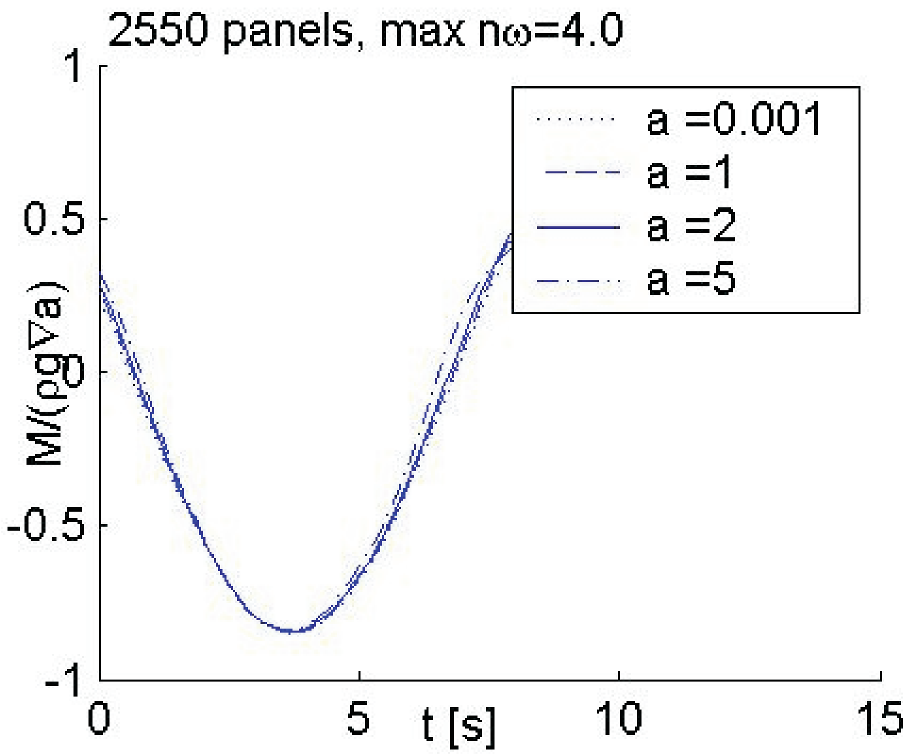

Figure 1: Time trace of one period of the diffraction part of pitch exciting moment

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Discusser: Q.W. Ma

My understanding is that you use a linear model for diffraction waves while you use the nonlinear model for incoming waves. I am wondering how you would justify that the nonlinear effects of diffraction waves could be ignored if the nonlinear effects of incoming waves are considered.

Author's reply:

The model we use to calculate the diffraction forces are non-linear in the sense that we use the below z=0 water velocities from the non-linear incoming waves. The part above z=0 is neglected in the diffraction calculation, so only a part of the non-linearities have been captured. The validity of this approach needs to be confirmed in the near future.