# SLOWDRIFT PHENOMENA IN IRREGULAR SEA

by

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Slowdrift behaviour of a moored ship in irregular sea is discussed. It is focused on slowdrift damping and response. Slowdrift excitation loads are briefly discussed. This has been a major research field for nearly twenty years. But still there seems to be important research areas associated with the second order potential, in particular connected with the radiation condition. The effect of short crested sea, viscous effects and the effect of current need further studies. The same is true for steep waves, where the second order perturbation solution breaks down. It is felt that there historically have been put to much emphasize on the slowdrift excitation loads and that the response and damping have been handled with too crude methods.

The hydrodynamic slowdrift damping components can be divided into skin friction damping, eddymaking damping and wave drift force damping. Before discussing the damping components in detail, the sensitivity of slowdrift response to damping is discussed. It is pointed out by an approximate method that the standard deviation $\sigma_x$ of the response is not very sensitive to the damping level. For instance for a quadratic damping model the standard deviation of the response is proportional to (-1/3) power of the damping coefficient.

The importance of the different damping components is discussed. Skin friction has only relevance for surge motions at very moderate sea conditions. Wave drift force damping is the dominant damping contribution to surge motion. In heavy sea it is

also likely to have some influence on sway and yaw motions, but the eddymaking damping seems to be the most important damping contribution for sway and yaw motion.

For typical midship sections the eddymaking damping is sensitive to bilge keel and bilge radius. The free surface and the beam/draft ratio have minor effect. The scale effect is not serious.

It is discussed how to obtain eddymaking damping terms experimentally and theoretically. Results obtained in a U-tube oscillating water tank is presented and compared with a single vortex method. The single vortex method represents the vorticity shed from a separation point by one single vortex. The time development of the vortex strength and position is determinded by a Kutta condition at the separation point and a zero-force condition on the sum of the vortex and the cut between the vortex and the separation point.

A Schwartz-Christoffel transformation is used to solve the problem. Any contour shape can be considered, but the separation point has to be known and fixed. The single vortex method shows good agreement with experiments at small KC-numbers for midship sections without bilge keels. But the single vortex method cannot explain the high experimental values due to bilge keel. A more elaborate calculation based on Faltinsen and Pettersen's thin shear layer model is presented. But it is shown that the thin shear layer model has difficulties.

The wave drift force damping is discussed in detail. A simple explanation of wave drift force damping can be given from a free decay test in surge motion of a moored ship in regular waves. Due to the regular waves the ship will experience an added resistance or mean drift force. It is well known that the added resistance of a ship is a function of ship speed, wave frequency and heading. The slowly varying surge motion can be interpreted as a quasisteady ship speed. This implies that the speed dependent term in the added resistance acts as a damping term.

Experimental data for wave drift force damping in surge is presented. It is pointed out that experiments based on free decay tests in regular waves are difficult to perform and that peculiarities happen close to the natural period in roll.
Present added resistance theories are not accurate enough to predict wave drift force damping. A theoretical approach intended to improve the state of the art is outlined. This is based on two-dimensional flow. The quasi-steady slow drift flow is represented by the single vortex method. The high frequency problem is the solution of incident regular small amplitude waves on a ship section in a quasi-steady flow. In the vicinity of the body the classical free surface condition cannot be used. It has only relevance at a distance away from the body. As long as the quasi-steady flow velocity is small this results in three wave systems downstream and one wave system upstream. It is discussed how to solve the boundary value problem and to find mean forces and wave drift force damping. It is pointed out that it is not straightforward to find wave drift force damping in irregular sea. This may have consequences for present day theoretical methods for surge slowdrift motion.

The last part deals with slowdrift surge, sway and yaw motion response of a moored ship in irregular waves. Experimental data from the Ocean Environrment Laboratory in Trondheim are presented. Both longcrested and shortcrested waves were examined. Each model test lasted for 1 hour. The theoretical solution was found in the frequency domain. Only longcrested sea was considered. Newman's approximation was used to estimate the slow drift excitation spectra and the quadratic damping term was linearized. This represent a simple approach compared to a time domain simulation, but strictly speaking it is only the mean and the standard deviation of the motion that can be calculated. The agreement between theory and experiments is satisfactory except for one heading in surge motion. The reason to the discrepancy is discussed.

The effect of short crested sea and the statistics of slowdrift motion is briefly discussed. A recommended "simple" numerical procedure for slowdrift motions is suggested.

Finally it is recommended that future work on slowdrift phenomena should concentrate on a) " wave drift-force" damping studies b) better mathematical model for surge c) effect of current d) effect of three-dimensional sea e) combined effect of wind, wave, current, thrusters and mooring f) statistics of slowdrift response.

## Discussion

Mei: We are using the Brown-Michael's approach to model oscillatory flow and are having some difficulties. Two questions:

1) You have computed the first half period up to the instant that $d\Gamma/dt = 0$. How did you use this limited information to calculate drag in an oscillatory flow after many flow reversals?

2) When modeling quasi-steady flow with single-vortex model, does this rule out the possibility of a Karman vortex street? In other words, is the single-vortex model sufficient?

Faltinsen: It is important to have in mind the motivation for using a Brown-Michael's approach. It is a practical way to examine general trends of $C_D$'s dependence on structural form. This is for instance impractical to do with a thin shear layer model as proposed by Faltinsen and Pettersen. On the other hand, Brown-Michael's approach represents a simplification. This means also that one may not achieve a more correct solution by proceeding beyond the instant that $d\Gamma/dt = 0$.

Let me then explain how $C_D$ was estimated. The ambient flow was assumed to be harmonically oscillating. The flow was started when the ambient velocity was zero and simulated to the point where $d\Gamma/dt = 0$. The drag force was calculated as a function of time and the drag coefficient was estimated by using the maximum drag force and maximum ambient velocity as parameters.

I feel one should use a method like Faltinsen and Pettersen's thin shear layer if one wants to advance the solution further in time with greater accuracy, but this method has its drawbacks. It neglects diffusion. Further, a major numerical difficulty occurs as the shear layer nears the separation points. It may be that one ends up solving the Navier-Stokes equations in the future.

To answer your second question one should keep in mind that the problem that was studied was a low Keulegan-Carpenter flow. Thus it is questionable whether the eddies generated from the two corners of the ship cross-section interact to form a Karman vortex street.

Hearn: We have recently completed a piece of work focussed more on providing approximate results than developing any specific theory for low-frequency damping. We have, in fact, already implemented the procedure Faltinsen suggested. This work was motivated by Wichers approach to the low frequency wave damping attributed to the apparent forward speed associated with the low frequency drifting of a moored structure. Inclusion of the small low frequency damping reduces the predicted surge motion and yields better agreement with measurements. Comparisons of our predictions with Wicher's experimental measurements for a 200,000 dwt tanker show that the strip theory method applied performs well at the lower frequencies. However, if too high a frequency is selected, the anticipated negative added resistance and hence negative slow drift damping coefficients are evident as suggested by Faltinsen today.

Stiassnie: A few years ago we did experiments on diffraction of waves by a fixed vertical plate. We used a very simple theory, based on the Haskind solution for the plate and on the single vortex assumption applying the Kutta conditions and the Brown-Michael assumption. The theory agreed surprisingly well with the experimental results. This work has been published in Proc. Roy. Soc. A 396 1984. It confirms Faltinsen's experience.

Troesch: Concerning the surge standard deviation plots where you show theory versus experiments. The standard deviation includes both the square of the mean and the mean square. Have you compared these as separate components, theory versus experiment?

Faltinsen: The mean values and the standard deviation about the mean value were compared separately. The results for the mean values were not shown. But the agreement between theory and experiments was not significantly better for the mean values than for the standard deviation about the mean values. One can only claim a partly satisfactory agreement.

Yue: I was very interested to see your results for short-crested waves. We have done some numerical experiments which indicate that the variance of the drift force can be larger when a wave pair propagates in opposing directions than in the same direction.

Faltinsen: I don't have experiments which support your observations.

Dommermuth: How is the Kutta condition satisfied? Where in the fluid is the Kutta condition satisfied (on the body or in the fluid)? What are the limitations?

Faltinsen: In the Brown-Michael solution the Kutta condition is satisfied at the separation point on the body surface. The Kutta condition implies that the separation point is a stagnation point. This is obviously an incorrect modelling of the flow in the vicinity of the separation point.