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Time-Domain Modelling and Analysis of a Transportation Barge in Waves With Focus on the Effect of Roll Damping

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Introduction

Barges are often used in transportation of platforms, like jackets. They are commonly built at construction yards far away from the installation site and then transported to the location.
Roll motion is in many cases dominant for forces in sea fastening systems and the barge will therefore be exposed to large roll motions. This can be critical as prediction of roll damping can be challenging. Most vessel responses can be calculated with acceptable accuracy in the frequency domain, whereas it is more difficult for roll response due to the nonlinear behavior of roll damping. Hence the challenge is to develop a reliable method for calculating the equivalent linearized roll damping which enables the required response statistics to be calculated in the frequency domain for operational strength and fatigue analysis.

Roll Motion

In the 1970's, strip methods for predicting ship motions in 5-degree of freedoms in waves were established. The methods are based on potential flow theories (Ursell-Tasai method, source distribution method etc.), and can predict pitch, heave, sway and yaw motions of ships in waves with fairly good accuracy [1]. Strip methods, however, do not work well on roll motion. The total roll damping of a floating vessel can be divided into potential and viscous components. The potential component can be predicted accurately since it has a linear characteristic, however the viscous component is non-linear and prediction of this is more problematic. Therefore, some empirical formulas or experimental data are used to predict the roll damping.

Equivalent Linear Damping

To simplify and limit the problem of nonlinear damping, one can formulate the roll motion as an equation of single degree [2], this can be seen in Equation 1.

$$(I_{44} + A_{44})\ddot{\eta_4} + B_{44}\dot{\eta_4} + C_{44}\eta_4 = F_4 \qquad (1)$$

Where $B_{44}(\dot{\eta_4}) = B_1\dot{\eta_4} + B_2\dot{\eta_4}|\dot{\eta_4}| + \cdots$ is the nonlinear damping coefficient in roll. In order to solve the equation in frequency domain, the quadratic damping term must be linearized.
For regular waves, the equivalent linear damping is found by demanding that the same amount of energy should be dissipated from the linear system as from the non-linear system. The equivalent damping in roll is shown in Equation 2 ([3]).

$$B_{44,2} = \int_0^T B_F \dot{\eta_4} \frac{\partial \eta_4}{\partial t} dt = 4\int_0^{\frac{T}{4}} B_2|\dot{\eta_4}|\dot{\eta_4}\frac{\partial \eta_4}{\partial t} dt$$
$$\implies B_{44,eq} = B_{44,1} + \frac{8}{3\pi} B_{44,2}\theta_0\omega \qquad (2)$$

For an irregular sea state the equivalent stochastic linearization is as shown in Equation 3 [4].

$$B_{44,eq} = B_{44,1} + 2\sqrt{\frac{2}{\pi}}\sigma_{\dot{\eta_4}} B_{44,2} \qquad (3)$$

Results in SIMA

The barge will have zero forward speed in the time domain simulations, as SIMA cannot handle analyses with forward speed. To achieve realistic results for a barge with forward speed some values had to be corrected. To avoid free rigid-body motions since we don't have any hydrostatic restoring effect in surge, sway and yaw, stiffness is added. Otherwise, the SIMA simulations will result into a very large offset in these horizontal motions. A proper damping is then also needed so that the resonant motions in these DOFs is reasonable

However the level of damping has great impact on the roll motion, especially in sway and roll as these are coupled with roll. As seen in Figure 1 and 2 the RAO for sway is very similar to that for roll, indicating the sway motion is due to the roll of the barge. When only the percentage of critical damping in sway is changed this has a huge impact on the RAO in roll. The damping should therefore be chosen with great caution.

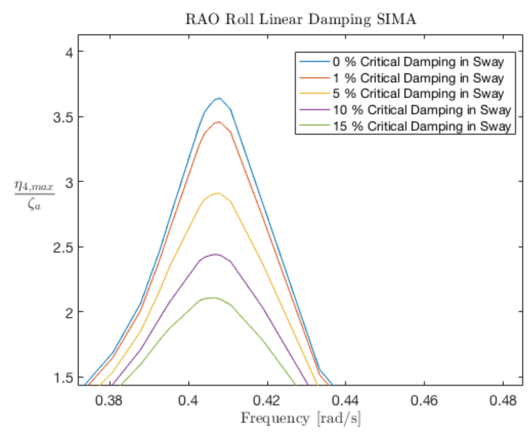

Fig. 1: Roll RAO with different Sway damping

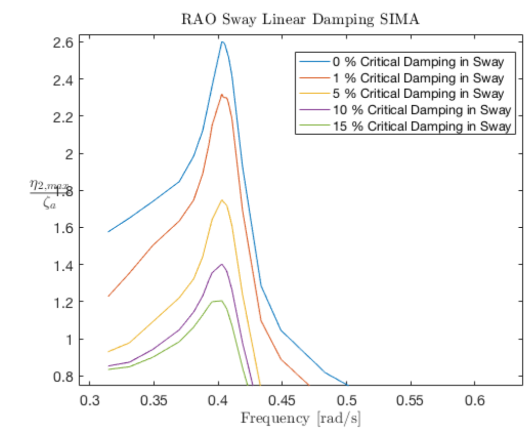

Fig. 2: Sway RAO with different damping

Comparison of Frequency and Time Domain Analysis

The RAO between the roll and wave amplitude are compared between the time and frequency domain solution. As seen in Fig. 4. It can be seen that the results in time domain has a bit lower natural period. This may be because SIMA uses damped natural frequency, while HydroD uses undamped natural frequency in the calculations. The amplitude is also lower for time-domain solution. This is due to strong coupled effects between roll, sway and yaw. As seen in the results in SIMA, the roll motion strongly depends on the percentage of critical damping in sway. As some damping has to be added to avoid large fluctuations in roll motion, the amplitude are effected.
In irregular waves, the roll response spectrum for time and frequency domain can be seen in Fig 4. The area under the graph $\int_0^\infty S(\omega)d\omega$, is proportional to the total energy in the roll motion $E/\rho g$. As seen from the figure, the area under the graph in time domain are larger, hence a higher total energy. In addition the response from HydroD has a higher and narrower peak, this indicates that the response are more concentrated around one frequency. While the response in time domain has a wider range of frequencies in the response, which means that the variance in frequencies are higher.

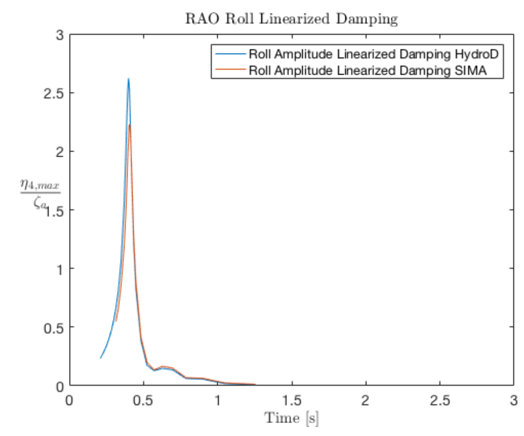

Fig. 3: Roll RAO in time- and frequency domain

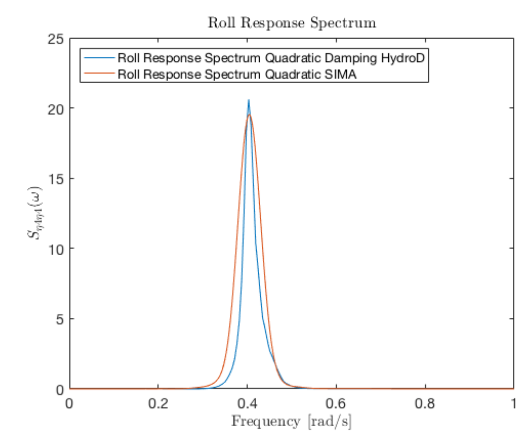

Fig. 4: Roll Response Spectrum in time- and frequency domain

Conclusion

The percentage of sway damping was chosen at the lowest level where the horizontal offset was acceptable and the roll motion reached steady state without fluctuations due to coupled effects. This happened at 1 % of critical dampin g in sway. The linearization of roll showed in Equivalent Linear Damping gives very similar results when both time and frequency domain simulations are ran in the same program. However it has been difficult to compare results from two different programs using different calculation techniques. In all simulations time domain solution has been more conservative than frequency domain, it is on the other hand hard to determine if this is due to different calculation techniques in the programs, coupled motions in SIMA or completely different causes.

References

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