Some aspects of slamming calculations in seakeeping

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Introduction

Slamming is a very important source of ship structural loading. Unfortunately, the hydrodynamic modelling of slamming is extremely complex and, still no fully satisfactory model exists. However, the 2D modelling of slamming is well mastered and is usually employed to assess the slamming loads on ships. Within the potential flow approach, which is of concern here, several more or less complicated 2D slamming models exist, starting from simple von-Karman model and ending by the fully nonlinear model. In between these two models there are several intermediate solutions such as Generalized Wagner Model (GWM) and Modified Logvinovich Model (MLM) which will be considered here. In addition, the 3D Generalized von-Kaman Model (GvKM) will also be discussed.

Seakeeping & Slamming

The slamming calculations are usually decoupled from seakeeping calculations. Simply speaking, this means that slamming is not influencing the ship motions, and this seems to be reasonable assumption for most of the typical ships. On the other hand, seakeeping itself is very complex problem and, it is also fair to say that, up to now there is no fully satisfactory seakeeping model for ship advancing with arbitrary forward speed in waves. However, some more or less accurate seakeeping models exist and they are introduced here in the context of determination of slamming conditions i.e. local geometry and relative velocity between the impacting surface and the sea water.

Determination of impact conditions

![Diagram of impact conditions](image)

Figure 1: Determination of impact conditions.

We consider linear seakeeping model and, in Figure 1, we show the typical impact situation which is likely to occur for a ship advancing in waves with forward speed $U$. The velocity of the point $P$ which is attached to the ship, might be written as:

$$v_B = \dot{\xi} + \dot{\Omega} \wedge (R_p - R_c) - U(\Omega \wedge i)$$

(1)
where $\xi$ denotes the translational velocity of the ship’s center of gravity $R_G$, the $\Omega$ is the corresponding rotational velocity, $R_P$ is the position vector of the point $P$ and $i$ denotes the unit vector in $z$ direction. On the other hand, the fluid velocity at the same point $P$ can be written in the form:

$$v_f = \nabla \varphi + U \nabla (\phi - z)$$

where $\varphi$ denotes the unsteady velocity potential and $\varphi$ the steady velocity potential. It is important to note that, within the linear approach, the velocity field can not be calculated above the mean free surface $z = 0$, so that the fluid velocity is calculated at the point $(X_P, Y_P, 0)$.

The relative velocity at point $P$ is the difference between the body velocity and fluid velocity:

$$v_R = v_B - v_f$$

Furthermore, within the 2D approach, the ship structure is subdivided into several strips with the direction defined by the vector $s$ (see Fig. 1), which means that the above defined relative velocity should be projected onto the strip direction:

$$v_R = (v_B - v_f) \cdot s$$

On the other hand, we also need to calculate the relative motion of the point $P$ in order to identify the time instant when slamming occur. Similar to the relative velocity, the relative motion between the point $P$ and the free surface, can be evaluated using the following formula:

$$\eta_R = Z_P + \zeta_P - \eta$$

where $Z_P$ is the initial position of point $P$ with respect to the initial free surface $(z = 0)$, the $\zeta_P$ denotes the vertical displacement of the point $P$ and $\eta$ denotes the wave elevation at $(X_P, Y_P, 0)$:

$$\zeta_P = [\xi + \Omega \times (R_P - R_G)] \cdot k, \quad \eta = -\frac{1}{g} \frac{\partial \varphi}{\partial t} - U(\nabla \phi - x) \cdot \nabla \varphi$$

With these notations, the impact will occur when the relative motion $\eta_R$ change the sign from positive to negative. Let also note that, usually one additional condition is also introduced in order to eliminate the cases with very low relative velocity. This condition, usually known as Ochi condition, states (eg. see [1]):

$$v_R \leq -0.988gL$$

where $g$ denotes the gravity acceleration and $L$ is the characteristic ship length (usually length between perpendiculars).

**Determination of critical sea state**

![Graphs showing maximum relative velocities for different sea states and time history of relative motion and velocity for a given sea state.](image)

Figure 2: Maximum relative velocities for different sea states (left) and time history of relative motion and velocity for a given sea state (right).

The main goal of slamming analysis is the determination of the design loads for a given ship and given operational profile (loading conditions, sea states, speed and heading). The sea states are usually defined by the scatter diagrams which give the probability of occurrence for different combinations of
wave heights and wave periods. In order to identify the design (worst) sea state with respect to slamming loads, first we need to perform the spectral analysis of relative velocities and relative motions, for all sea states contained in the scatter diagram. One typical result of these calculations is shown in Figure 2. From these diagrams, we can deduce the critical operational conditions (combination of the sea state, loading condition, speed and heading) when the maximum relative velocities occur. Once the critical operating conditions has been identified, the time domain simulations are performed for this particular sea state and exact impact conditions determined using the expressions described in the previous section. One typical time signal of the relative motion and relative velocity is shown in Figure 2.

**Different slamming models**

As briefly stated in the introduction, it exist several models for determination of slamming loads. Most of them considers the impact and/or water entry problem i.e. problem of body entering the calm water surface with the prescribed velocity. The simplest model is the so called von-Karman model and is "followed" by the well known Wagner model. The main difference between these two models is the determination of the wetted part $c(t)$ of the body, as shown in Figure 3. Indeed, the von-Karman model assumes the wetted part as the intersection of the body with the initial free surface, while, in the Wagner model, the wetted part of the body is unknown in advance and is the part of solution. Both models linearize body and free surface conditions. The Generalized Wagner Model (GWM) [8], represents an improvement of the Wagner model in the sense that the body boundary condition is satisfied on the exact body surface. On the other hand the so called Modified Logvinovich Model (MLM) [2] is the approximate second order model, which satisfy the body condition up to second order and accounts for the quadratic term in Bernoulli equation. The main advantage of the MLM, when compared to GWM, lies in its simplicity and in comparably lower CPU time requirements. However in general, the overall MLM slamming forces seems to be very close to GWM model as shown in Figure 4. In this paper more systematic comparisons will be made in order to justify the efficiency of the MLM model, which has much more practical importance in the context of the long time whipping simulations (overall structural ship response to slamming) which become more and more required for large ships.

As far as the 3D slamming methods are concerned, the methods are less developed, the main reason being the difficulty in determination of the wetted part of the body. That is why the so called 3D Generalized von-Karman Method (GvKM) becomes interesting. Indeed, the wetted part of the body being known at each time step, efficient 3D panel methods can be applied to solve the associated von-Karman boundary value problems. One example of the results for a typical ship is shown in Figure 5. We can see that the numerical results agree reasonably well with experiments. In spite of the limitations of the GvKM, it is
likely that this model will take into account 3D effects more properly, than the 2D strip methods. Thus, we can hope to identify relatively simple 3D corrections to the 2D strip approaches and be able, in the end, to calculate the 3D slamming loads within the reasonable CPU time.

Conclusions

In this paper, the 2D slamming methods are revisited and 3D Generalized von-Karman Model investigated. It is clear that many objections can be made to any of the described approaches, in the case of very general 3D ship slamming problem but, in the absence of fully satisfactory 3D model, we believe that useful step can be made by combining all these methods into a simple tool which is missing in engineering practice.

References

