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Hydro-structural issues in the design of ultra large container ships

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ABSTRACT: *The structural design of the ships includes two main issues which should be checked carefully, namely the extreme structural response (yielding & buckling) and the fatigue structural response. Even if the corresponding failure modes are fundamentally different, the overall methodologies for their evaluation have many common points. Both issues require application of two main steps: deterministic calculations of hydro-structure interactions for given operating conditions on one side and the statistical post-processing in order to take into account the lifetime operational profile, on the other side. In the case of ultra large ships such as the container ships and in addition to the classical quasi-static type of structural responses the hydroelastic structural response becomes important. This is due to several reasons among which the following are the most important: the increase of the flexibility due to their large dimensions (Lpp close to 400 m) which leads to the lower structural natural frequencies, very large operational speed (> 20 knots) and large bow flare (increased slamming loads). The correct modeling of the hydroelastic ship structural response, and its inclusion into the overall design procedure, is significantly more complex than the evaluation of the quasi static structural response. The present paper gives an overview of the different tools and methods which are used in nowadays practice.*

KEY WORDS: Hydro-structure interactions; Hydroelasticity; Springing; Whipping; Slamming; Potential flow; Boundary integral equation method; Finite element method; CFD; Model tests; Full scale measurements.

INTRODUCTION

Even without considering the ship's structural responses, the numerical modeling of the ship hydrodynamic behavior remains an open problem for a general case. This is true both for the most commonly used potential flow models and for the general CFD codes based on solving directly the Navier Stokes equations. The main problems of the modeling concern the correct representation of the waves generated by the interaction of the body with the sea waves. Indeed the presence of the free surface which is not only unknown in advance but, at the same time, supports a highly non-linear boundary condition makes the solution of the general seakeeping problem extremely difficult. The impossibility to solve the complete non-linear seakeeping problem at once forces us to introduce the different levels of simplification.

On the structural side the situation is slightly less complex because, usually, the linear structural problem is considered only. Nowadays very efficient numerical tools exist based on Finite Element Method (FEM) which allows solving any type of linear structural problem either in quasi static or dynamic sense. This means that, once the correct hydrodynamic loading is transferred to the FEM model, the evaluation of the structural response is rather straightforward. This load transfer from one model to the other is nevertheless an important and delicate step that needs to be done in an accurate way.

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The practical procedure for ship structural design involves the verification of two main structural failure modes:

- Yielding and buckling in extreme conditions
- Fatigue initiated cracks

These two failure modes are fundamentally different and the methodologies for their assessment are also different even if many common points exist. The final goal of the extreme event analysis is to predict, for each structural member, the single most likely worst event during the whole ship life while the goal of the fatigue analysis is to analyze the whole ship life by counting all the combinations of the stress ranges and the corresponding number of cycles for a particular structural detail.

For the classical ships (tankers, bulk-carriers, general cargo ships …), not exceeding certain size, the usual design practice passes through the direct application of the prescribed rules and procedures issued by different Classification Societies. In the case of extreme structural response, these procedures do not involve fully direct hydro-structure calculations and the final design load cases are given in the form of the equivalent simplified load cases which are constructed as a combination of the different prescribed design loads. Even if the procedure for the determination of the design loads relies partially on hydrodynamic calculations, the rule approach remains basically prescriptive approach with an important part of empiricism. On the side of the structural strength, other safety coefficients are introduced and the final calibration of the rule approach is done using the extensive feedback from experience which ensures the excellent safety record of the existing ships. Due to these calibration procedures it is not possible, in principle, to use the rule procedures for a novel designs which do not enter in the initial assumptions of the considered design (ship type, size…) and operations. As far as the fatigue life is concerned the rule approach uses the similar equivalent load case approach. Within this approach, the stress distribution is assumed to follow a Weibull distribution which is described by two parameters: a shape parameter and a reference stress corresponding to a given probability level. This reference stress is computed using the similar equivalent load case approach..

Within the so called direct calculation approach for the assessment of the ship structural reliability, the basic idea is very simple: the structural response of the ship should be directly calculated during whole her life using the fully coupled hydro-structural models and the identification of the extreme events and fatigue life will be determined directly. Since the fully consistent non-linear hydro-structure calculations are not practically possible, within the reasonable combination of CPU time and accuracy, one must consider some approximate solutions using the different levels of approximation at different steps of the overall methodology. One of the main purposes of the present paper is to discuss the actual state of the art of the different models.

HYDRO STRUCTURE INTERACTION MODELS

Before entering into the details of the different numerical models, let us first classify the different hydro-structural issues. In Table 1 these different issues are schematically separated with respect to the nature of the hydrodynamic loading and the nature of the structural response.

Table 1 Different hydro-structural issues (H - hydrodynamics, S - structure).

H \ ***S***	Linear	Wave non linear	Impulsive non linear
Quasi static	***X***	***X***	***X***
Dynamic	***X***	***X***	***X***

As far as the hydrodynamic loading is concerned, the usual practice is to classify it into 3 different categories:

- linear hydrodynamic loading
- weakly nonlinear, non-impulsive loading
- impulsive hydrodynamic loading

Within the potential flow hydrodynamic models, which are of main concern here, the linear hydrodynamic loading means the classical linear diffraction radiation solution also called the seakeeping hydrodynamic analysis. The weakly non-linear loading means the non-impulsive part of the wave loading which is usually covered through the different variants of the so called Froude Krylov approximation which is combined with the large ship motions. The impulsive loading includes any type