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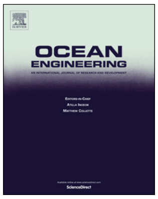

On high-speed craft acceleration statistics

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ABSTRACT

Design and operation of high-speed planing craft is ruled by the hydrodynamic impact loads and the related craft responses occurring at violent wave encounters. Simulation, measurement and characterization of these loads and responses is however far from trivial. Hereby the general knowledge about these processes is actually rather limited and it is common to rely on simple semi-empirical formulas when designing and analyzing high-speed craft. This paper presents a unique set of impact acceleration data for a high-speed craft in waves, generated based on non-linear strip simulations. Methods and measures for statistical characterization of the acceleration process are established and evaluated, and by application of these methods on the simulation data a number of issues are clarified, for example: slamming time scales and selection of appropriate sampling rates and filtering levels; identification of peak values in acceleration signals; statistical distributions and convergence; and the relation between the statistical peak fraction averages that are commonly used as design parameters and the actual extreme values. The established methods and generated results form a valuable basis for setting up and analyzing high-speed craft experiments and simulations, and for validating and updating the prevailing semi-empirical methods.

1. Introduction

Operation of high-speed planing craft in irregular seaways involves complex hydrodynamics. The interaction between the craft and the stochastic waves typically result in large relative motions where the craft impacts the wave surface at high velocities. These high-speed impact events cause peaked hydrodynamic pressure distributions which rapidly traverse the hull bottom, resulting in large magnitude vertical accelerations. The magnitude and character of the impact loads depend on the relative velocity and the relative geometry between the hull and wave surface, which in turn depend on craft speed, running attitude and seastate. These impact loads stress the craft structure, the on-board systems and the crew, and often limit the operation. To design and operate high-speed craft efficiently it is essential to understand the involved physics and to quantify these loads, both from craft structural integrity and crew safety and comfort points of view.

The vertical accelerations related to slamming impacts are today often characterized using statistical peak fraction averages, such as the average of largest 1/10th or 1/100th peak accelerations. These measures are used for determining design loads for the craft structure through fundamental work such as Savitsky and Brown (1976) and Allen and Jones (1978), which are implemented in virtually all classification society rules that govern high-speed craft design (e.g. DNV, 2013 and ABS, 2013). The conditions for the crew are also characterized using peak fraction averages, for example using the ride quality index (Riley et al., 2010a), and limiting criteria such as in Koelbel (1995) and Riley et al. (2014). Comparative analysis of craft performance regarding seakeeping properties is also commonly based on vertical acceleration peak fraction averages.

There are in principal two ways to determine vertical acceleration peak fraction averages: from time series of simulated or measured acceleration response, or through semi-empirical formulas using craft main particulars and principal seastate parameters (e.g. Fridsma, 1971; Hoggard and Jones, 1980; Savitsky and Brown, 1976).

Simulation or measurement of the acceleration process is far from trivial. Selection of the proper time step or sampling rate, and runtime to obtain converged statistics, is for example discussed in Zseleczky and Mckee (1989), Zseleczky (2012), Savitsky and Koelbel (1993), Rosén and Garme (2004) and Riley et al. (2010a, 2010b), the conclusions are however not in agreement. The recommendations in ITTC (1999) states that a minimum of 100 wave encounters shall be considered, however for calculation of

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the average of the largest 1/100th peak acceleration values this is obviously too little. Low-pass filtering of, and peak identification in, the acceleration process are also challenges. In McCue et al. (2012) the effect of filter characteristics and cut-off frequencies on the resulting statistics are investigated, no conclusive recommendations are however presented. Peak identification methods have been presented in Zselesky (1989), Taunton et al. (2011), and in Riley et al. (2010a) where an encouraging attempt to standardize the process of both filtering and identifying peaks through the Standard-G method is outlined. The effects of filtering and the peak identification parameter selections on the resulting statistics do however deserve further investigation.

Acceleration peak fraction averages are nevertheless proven to be useful in design and analysis of high-speed craft. It must however be realized that for the high-speed craft system, it is rather the extreme values that will be the ultimate limit, either due to structural failure or crew injuries. It is therefore important to understand the relation between peak fraction average statistics and the extreme acceleration values. Methods for calculation of extreme values are well established (e.g. Ochi, 1981) and are commonly applied for larger ships (e.g. Wu and Moan, 2006a). Examples of acceleration extreme value analysis for small high-speed craft are however few (e.g. Garme and Rosén, 2003; Rosén and Garme, 2004; Rosén, 2004; McCue, 2012).

The semi-empirical formula for predicting vertical accelerations in Savitsky and Brown (1976) is based on the research of Fridsma (1971), where extensive systematic model scale measurements of high-speed craft acceleration response in irregular waves were performed. It was concluded that the acceleration peaks followed the exponential distribution and peak fraction averages, such as the 1/10th or 1/100th largest values, were suggested to be derived based on the average peak acceleration. Recent research has however shown that this gives a rather poor fit to the actual sampled peak value distributions (e.g. Grimsley et al., 2010; McCue, 2012; Bowles and Soja, 2014).

As stated, structural design of high-speed craft is based on the concept of a design acceleration. Koelbel (1995) even states that the single most pressing matter for improving the accuracy of the prevailing semi-empirical design method relates to the determination of the design vertical acceleration. In Razola et al. (2014) it is concluded that the prevailing slamming design pressure prediction formulas still have merit, but that better understanding of the design vertical acceleration statistics is crucial.

It is clear that vertical acceleration statistics plays a central role in the design and operation of high-speed craft, however, measurement and statistical characterization is still a challenge. In summary five specific research questions related to these challenges are formulated:

- How to select simulation time step, sampling rate and filtering levels with appropriate consideration of the typical slamming time scales?
- How to set up simulations or experiments to reach statistical convergence?
- How to identify peak values in impact acceleration time series?
- How are acceleration peaks distributed statistically?
- How to calculate extreme values?

These questions are here addressed by generating an extensive set of acceleration data using a non-linear strip method. The craft speed and sea states are systematically varied and simulations extend to three hours for each condition. Statistical analysis methods are established and applied on the data to enable characterization of the acceleration process in terms of slamming time scales, peak value distributions, peak fraction averages and extreme values. Finally, the results are synthesized to answer the outlined research questions and used as a basis for discussing some practical implications for high-speed craft design.

2. Hydrodynamic simulations

The acceleration process is stochastic and a compound of several different physical mechanisms. This can manifest itself in rare, severe impact events, which are important for example from craft structure integrity and human factors perspectives. Characterization of these processes requires large data samples which typically translates into long measurement or simulation times. For the purpose of this study, where a large set of conditions is considered and large samples are required, numerical simulations are used. The craft dynamics are simulated using a non-linear strip method, where pitch and heave responses are modeled at constant speed in head seas. The non-linear strip method is a good compromise between accurate representation of the involved physics and efficient use of computational resources. Principally, the section forces are modeled based on the force contributions from the added mass rate of change, the Froude-Kriloff components, and the hydrostatic components, all related to the momentary immersed hull section areas. The equations of motions are formulated from Newton's second law and solved by iteration in the time domain with a time-step of 0.005 s. The method used in this study has been well validated regarding the resulting motions and accelerations for Froude beam numbers of $C_v > 2$ (Garme and Rosén, 2003; Garme, 2005).

The study considers a 10.5-m high-speed craft with a mass of 6500 kg, a beam of 2.5 m and a deadrise of 22° at the transom. The longitudinal center of gravity is located 3.7 meters forward of the transom and the vertical center of gravity is 0.92 m above the keel. The hull geometry can be seen in Fig. 1. Speeds and sea states have been systematically varied to cover a broad range of operational

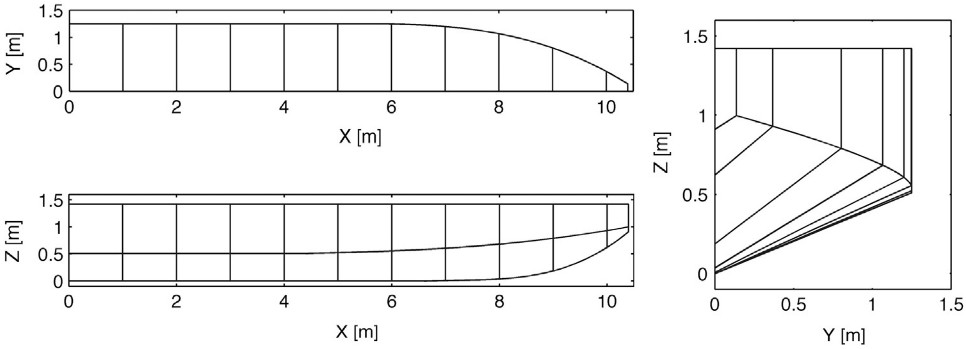

Fig. 1. Lines plan of the 10.5 m high-speed craft.